SITUATED ARGUMENTATION, LEARNING AND SCIENCE EDUCATION:
A CASE STUDY OF PROSPECTIVE TEACHERS’ EXPERIENCES
IN AN INNOVATIVE SCIENCE COURSE

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by

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ABSTRACT

Various authors have called attention to the significance of argumentation in science education. Nevertheless, argumentation practices have been considerably rare in science classrooms. Moreover, little is known about how people engage in argumentation as science learners to construct knowledge about the natural world and about science.

This study was conducted in a science course for prospective teachers (PTs) offered in the College of Education at a large university in the northeastern United States. The course was structured around three instructional units (modules), focusing on evolution, light, and global climate change. In each module, PTs were confronted with scientifically-oriented questions, and working in pairs, they built evidence-based arguments. Various types of technology tools were used to support PTs in the process. The study addresses the experiences of four prospective teachers through a case study research design informed by grounded theory and phenomenology theoretical frameworks. The research questions were: (1) How do prospective teachers (PTs) perceive the experience of engaging in the process of situated argument construction as students in a innovative science course? (2) What factors account for PTs’ experiences in situated argument construction? and (3) What are the participants’ perceptions of learning that emerged from the context of the process of argument construction in SCIED 410? The primary sources of data for the study were electronic artifacts constructed by PTs and interviews with participants conducted after each unit, plus a follow-up interview. The structure of the participants’ arguments was analyzed to determine the extent to which the PTs explored multiple explanations, provided relevant evidence to support their conclusions, explained how evidence and conclusions were related, and recognized limitations in explanations. Interviews were analyzed using methods from grounded theory. Open and axial codes were generated through comparisons of data to develop concepts that reflected the participants’ perceptions of the process of argument construction and perceptions of learning emerging in the context of this process.
The results indicate that situated argument construction for PTs involved two major processes: *argument building as legitimization* (or the use of the argument structure to make one’s argument valid and acceptable) and *argument building as means to understand* (or the use of argument in facilitating or inhibiting the process of development of explanations to better understand a problem). In the first case, the focus is on gaining authority; in the latter, the focus is on gaining ability to construct explanations. These processes were not mutually exclusive as participants experienced them in the same investigation at different stages and in different situations. Nevertheless, argumentation as legitimization prevailed.

The participants’ perceptions of learning were, in part, considerably homogeneous. PTs tended to see learning as the acquisition of information, and as distinguishing accurate from inaccurate answers. However, the participants perceived the role of the instructors differently. On one hand, some PTs expected the teachers to give them answers, whereas others saw the teacher as a facilitator who should provide guidance for the students to find answers on their own.

Multiple factors were identified as accounting for the variation in PTs’ experiences with argument construction: (1) the context of the school, including characteristics of task, resources, and power relations; (2) the learner orientation, including PTs’ understandings of the process of knowing and of what is to be known; (3) the context of science, including PTs’ dispositions toward science, proficiency with science, and definitions of science. All these factors interacted with each other to produce diverse experiences with argumentation in SCIED 410.

Various conclusions were drawn from the study. First, knowledge of the importance of assessing participants’ perceptions in constructing more robust understandings of learning experiences was generated. Second, a much more complex notion of the experience of argumentation in science education, which involves multiple processes and embedded networks of interactions, was developed. Finally, through exploring these complexities and the situated nature of argumentation, new dilemmas and new goals for science education were identified.
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Com Amor
Chapter 1
Introduction

1 Introduction

What happens when students read from a science textbook and find information about protozoa, gravity, or the seasons? What is going on when students listen to their teacher explain natural selection or the structure of the DNA? What is taking place during a chemistry lab when students follow directions to identify endothermic reactions? We cannot read our students’ minds to tell the complete story underlying these “school episodes,” but we can predict that some things are not going to happen. For instance, it is hard to imagine that someone in the middle of the lecture would raise her/his hand and say: “How can we be sure the DNA is the genetic material?” “How did that person come up with such model?” It is even less likely that a student would write the following on a quiz: “I don’t agree with what was written in the text book. For me, is much more reasonable to think that, during the year, the earth get closer and farther from the sun, and that produces different seasons” or “I don’t think this category, Protozoa, is useful at all in my life. It doesn’t mean anything to me.”

Interestingly, teachers probably would not raise those issues either and do not see them as pertinent questions for science learning. There is a willingness to accept all the information that comes from science, and that we can trust the accuracy of science. Scientists have a unique way of discovering things – a way of thinking that is so different from ordinary people that it is accessible only to “special” people. Scientists have a way of thinking that is the best and sole way to understand the natural world. Yes, maybe we should be content with knowing the scientific information, that is, “scientifically accepted facts,” and with trying to use it somehow in ‘real-life’.
This position, predominant among students and science teachers, makes visible many assumptions that prevail in school science, in particular, assumptions about what science is and what it is to learn. First, I recognize the assumption that the process through which knowledge originates is not an important aspect of science and learning. Thus, an image of knowledge dissociated from process of knowledge construction is conveyed. A second assumption, deriving from the first, is that since knowledge is dissociated from process, it comes to represent the reality. In other words, as the process of scientific knowledge construction is ignored in the classroom, science starts to represent the natural world as it is, instead of a useful interpretation of nature. Thus, science is not perceived a human endeavor connected to its social-cultural-historical context. Moreover, an assumption about learning also derives from the first assumption that it is possible to understand facts without understanding the reasoning and experiences behind these “facts.” The forth assumption that I recognize is that someone else knows how to find out how the reality is, but as student, one does not participate in the construction of knowledge about nature. In other words, students are mere consumer of scientific knowledge. In this context, a fifth assumption is derived: to learn science becomes to the ability to consume (or possess) scientific knowledge. We should remember that this assumption rests in the notion that scientific thinking and ordinary thinking have little in common.

Argumentation had been recognized as a practice that has the potential to challenge the assumptions described above in the context of school science (Driver, Newton, & Osborne, 2000; Kuhn, 1993; Newton, Driver, & Osborne, 1999). First, learners can experience scientists’ practices that would situate knowledge in its original context (Brown, Collins, & Duiguid, 1989) as well as have opportunities to learn about science, not merely science concepts (Driver, et al., 2000; Osborne, Erduran, Simon, & Monk, 2001). Second, learners’ understandings and thinking can become more visible (Bell & Linn, 2000), representing a tool for assessment and self-assessment (Sandoval & Reiser, 1997a; Zembal-Saul, Munford, Crawford, Friedrichsen, & Land, 2001). Third, argumentation can support learners in developing different ways of thinking (Kuhn,
1991, 1992, 1993), and facilitate science learning, taking into consideration the role of language, culture and social interaction in the process of knowledge construction (Pontecorvo, 1987). Finally, through argumentation, science learners become producers of scientific knowledge and not merely consumers of this knowledge (Brown, 1998; Candela, 1998).

The present study refers to an initiative to engage prospective teachers in science learning, which is associated with practices of scientific knowledge construction. Prospective teachers, majoring in different areas, participated in argumentation in the context of a science education course. The prospective teachers’ perspectives and perceptions of that experience are explored in this case study. Grounded theory and phenomenology were used as theoretical frameworks in this study.

2 The problem

Conceptual tools similarly reflect the cumulative wisdom of the culture in which they are used and the insights and experience of individuals. Their meaning is not invariant but a product of negotiation within the community... Activity, concept, and culture are interdependent. No one can be totally understood without the other two. Learning must involve all of the three. Teaching methods often try to impart abstracted concepts as fixed, well-defined, independent entities that can be explored in prototypical examples and textbook exercises. But such exemplification cannot provide the important insights into either the culture or the authentic activities of members of that culture that learners need.” (Brown, Collins, & Duiguid, 1989, p. 33).

This quote has two components that are extremely valuable to the science educator/researcher. First, it presents different notions of knowledge and learning that should, in the opinion of the authors, orient school science practices. Second, from these notions of learning, it poses a critique to the current practices, making transparent the limitations of the assumptions that underline them.
Within this perspective, the consequences of the assumptions described in the introduction are not surprising. First, research indicates that in science classrooms (as well as outside school) there is little understanding of fundamental scientific concepts (e.g. Bishop & Anderson, 1990; Driver, Guesne, & Tinberghien, 1985; Rye, Rubba, & Wiesenmayer, 1997). Furthermore, there is little understanding of how scientists construct knowledge, and consequently there is a mystification of science and scientific knowledge (Driver, Leach, Millar, & Scott, 1996; Lederman, 1992). Brown et al. (1989) argue that such problems derive from the very notions of knowledge and learning that inform classroom practices, and make a call for a change in the culture of classrooms. Reiser, Tabak, & Sandoval (2001) bring this propose to the context of science education:

To create inquiry classrooms in which students learn through investigation requires basic changes in the rules of the game for science classrooms – new curricula and tools must be accompanied by new teaching approaches and an explicit attention to shifting students’ attitudes toward science and science learning. Engaging students in this type of learning requires different values and expectations. It requires creating a different type of classroom culture. (p. 2)

The goal of producing such a change in classroom culture can be described, in part, as making school science more authentic. First, it is recognized that knowledge is constructed within a context (Brown et al., 1989; Edelson, 1998; Roth, 1995). Thus, presenting science concepts in an isolated manner, disconnected from their socio-historical and practical contexts, would not reflect “authentic science.” Most important, this kind of instruction would result in a quite limited understanding of science, and learners would be unable to use such knowledge in more complex situations, both inside and outside school (Edelson, 1998, 2001).

A second important aspect that the current notion of authentic science comprises is that science is more than scientific concepts, tools and techniques. Authentic science in the classrooms should also embrace “scientists’ attitudes and their social interactions” (Edelson, 1998, p. 318). Thus, questions to be investigated in the classroom have to be meaningful to learners, so students, like scientists, have a commitment to their
investigations. Moreover, since scientific knowledge is socially constructed, school science should emphasize interaction and communication among peers (and whenever possible with scientists, the community, etc.) (Edelson, 1998; Roth, 1995).

Despite the awareness of the need to change school science culture, the challenge of making it a reality is still present. A positivist view of science still prevails in science school. Science is presented as a collection of facts, and the practice of science is portrayed as purely empirical. In schools, students read from textbooks, memorize concepts and, in the best-case scenario, perform experiments in which they follow directions to confirm what the teacher told them (Millar, 1989; Rudolph & Stewart, 1998; Taylor, 1998). In contrast, little attention is given to an essential aspect of science and scientific thinking – the process of argumentation (Driver et al., 2000). That is, how through revising theories, generating and interpreting evidence, scientists build explanations in a social context (Driver et al., 2000; Jimenez, Rodriguez, & Duschl, 2000; Kuhn, 1993), and how this way of thinking can support students in participating in the construction of their scientific understandings (Candela, 1998).

In the context of school, argumentation would involve engaging in scientifically oriented questions, giving priority to evidence in responding to questions, formulating explanations from evidence, connecting explanations to scientific knowledge and communicating and justifying explanations (National Research Council, 2000, p. 29). “Doing science” at school through these activities would represent a shift in the focus of teaching, that is, less emphasis on “science as exploration and experiment” (or hands-on activities) and increasing emphasis on “science as argument and explanation” (or minds-on activities) (Abell et al. 2000; Kuhn, 1993; National Research Council, 1996).

Nevertheless, it is extensively recognized that, as students are asked to learn in the context of such new culture and engage in scientific inquiry, they face various difficulties (Krajcik, Blumenfeld, Marx, & Soloway, 2000). Moreover, there are also many difficulties related to the process of building arguments in particular. First, students' arguments seem to lack important components, such as evidence to support their claims and justification that connects claims to evidence (Driver et al., 2000; Jimenez et al.,
Second, learners have trouble developing strategies to engage in scientific inquiry and argumentation, both in terms of general strategies (Krajcik et al., 2000; Kuhn, 1991, 1993) and domain-specific strategies (Sandoval & Reiser, 1997; Tabak & Reiser, 1999). The efforts to overcome these challenges have taken a variety of forms. However, one of the biggest potential barriers to a change in classroom culture that has been recognized is the lack of resources and minimal preparation of teachers with regard to supporting her/his students throughout that process (Driver et al., 2000; Newton et al., 1999; Zeidler, 1997).

Although the important role of the teacher in supporting students' inquiry, and particularly argumentation, has been recognized, as teacher educators, we know very little about how to provide valuable experiences to future teachers in ways that support them in developing strategies to teach science in authentic ways. A reasonable recommendation is to first have prospective teachers engage in authentic science learning (National Research Council, 2000; Putnam & Borko, 1997, 2000). Prospective teachers’ experiences as learners would be the starting point for developing different notions about teaching and learning science, and, later on, different instructional strategies. Nevertheless, teachers rarely engage in authentic science learning and little is known about their experiences in such contexts or what influences such processes. In this study, I intend to contribute to the field’s understanding of these issues.

3 The Purpose of the Study

The purpose of this study is to explore the nature of prospective teachers’ experiences as they engage in argumentation to learn science at school. More specifically, this study will examine how prospective teachers perceive their experiences in a college level science education course in which they were required to build evidence-based arguments to respond to scientific questions. First, participants’ understandings about argumentation in science were explored by examining the arguments that they
generated through that experience, focusing on instructors’ perspectives, which were informed by studies within the science education community and argumentation theory. Then, the experience of argument construction from participants’ perspectives was examined and contrasted to instructors’ perceptions of this same experience. All these aspects were explored throughout the semester in a way that permitted me to have a sense of whether and how these perspectives changed through time. Finally, the present study intends to go beyond providing a description of participants’ experiences. I intend to construct an explanation of participants’ notions about engaging in argumentation in science learning to understand some of factors that are related to such understandings.

4 Research Questions

The research questions of the present study were:

1. How do prospective teachers (PTs) perceive the experience of engaging in the process of situated argument construction as students in an innovative science course?
2. What factors account for PTs’ experiences in situated argument construction?
3. What are participants’ perceptions of learning that emerged in the context of the process of argument construction in SCIED 410?

The first question was designed to examine and describe prospective teachers’ notions of the process of argument construction in the context of school science. First, this question is centered in understanding the experience of argument construction as lived by participants in a specific context. Second, argument is considered as situated, thus, to answer the research question “entails asking a number of others: What does argument do? Who does it? With or to whom? Where? and Why? Each of these questions links an understanding of argument not to the realm of the abstract and immutable but to the social, interactional world, or more precisely, worlds.” (Costello & Mitchell, 1995, p. 1-2). It is important to note that the major focus of the research was on
learning about argument construction as experienced by prospective teachers, not in verifying whether and when argumentation, as understood by instructors (or the science education community), occurred. My goal is to enrich our understandings of argumentation through the rich description of participants’ experiences.

The second question refers to going beyond the interpretation and description of PTs’ experiences and trying to construct an explanation for the patterns reflected in such a description. The need for explanation has been frequently associated with the positivist notion of causality. In accordance with this notion, to explain a phenomenon, one must establish very specific relationships between, namely, temporal precedence, physical contiguity, constant conjunction (or recurrent regularity) (Lincoln & Gubba, 1985, p. 134).

I agree with Lincoln and Gubba (1985) that the notion of causality should be abandoned and other forms of explanation must be adopted. In the present study I approached this question using the concept of mutual simultaneous shaping, trying to understand the pattern of relationships of various factors. These relationships are not unidirectional, and do not need to occur separated in time, as would be expected considering the positivist notion of causality. Moreover, within this perspective, the explanation that is constructed is contextualized in the sense that it refers to a configuration of interacting factors. Thus, explanations become “‘here-and-now’ accounts that represent a ‘photographic slice’ of life of a dynamic process” (Lincoln & Gubba, 1985, p. 155). The third research question emerged during the process of data analysis, as described in Chapter 4 (see p. 132).

5 Significance of the Study

This study of prospective teachers experiences with argumentation in science learning is significant because of its potential of contributing to scholarly research, its significance for policy, and its significance for practice. Most studies on argumentation in school science involve K-12 students as learners (e.g., Jimenez et al., 2000; Kelly et
Thus, little is known about how adult learners engage in and understand argumentation in a specific discipline, and in the context of schooling. Studies with adults have focused on informal argumentation or argumentation outside the realm of science (Kuhn, 1991, 1992, 1993; Marttunen, 1994; Marttunen & Laurinen, 2001). The present study can illuminate our knowledge about these aspects, and, consequently, has the potential to contribute to a better understanding of the developmental aspects of scientific thinking (Kuhn, Amsel, & O’Loughlin, 1988). Thus, the present study has significance for theory in the area of science education, as well as in the general area of cognition.

Moreover, in the present study, learners’ perspectives were taken as central to the development of a theory of argumentation in science learning (and learning in general). Past studies with argumentation involved the mere “analysis” of participants’ behavior within a certain theoretical framework. This type of research has an empirical base, however, to what extent is its base robust if no further dialogue is established with learners (or argument constructors) who experience argumentation? Theory is no substitute for experience – theory and experience complete each other (Smith, 1999). Experience in not unequivocal and one-dimensional, researchers must start to look for the participant’s facet of experience otherwise theories on argumentation are deficient.

The present study also has the potential to inform policy makers. Contemporary reform documents such as the National Science Education Standards (National Research Council, 1996) and Inquiry and the National Science Education Standards: A Guide for Teaching and Learning (National Research Council, 2000) have served as guidelines that orient science education policies at the national and local levels in the United States. These documents include recommendations in the areas of teaching, curriculum development, assessment, professional development and teacher education. Frequently, local standards are elaborated based on such recommendations, assessment instruments are designed based on local and national standards, curriculum is designed taking into account these documents, textbooks are written using some of these guidelines, professional development initiatives follow its recommendations, teacher certification
requirements are established to concur with such guidelines, and so on. However, more research is needed to better understand some aspects that are promoted in these documents.

One of the essential aspects of the reform, identified as one set of the “unifying concepts and processes” in the National Science Education Standards (National Research Council, 1996) is “evidence, models and explanation.” These key ideas are directly related to argumentation. They are further described in Inquiry and the National Science Education Standards (National Research Council, 2000). In accordance with this document, in an exemplary science classroom, “Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions;” learners formulate explanations from evidence to address scientifically oriented questions; learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding; and finally, learners communicate and justify their proposed explanations” (National Research Council, 2000, p. 11).

Another important aspect in these reform documents refers to recommendations on how science teachers education programs and professional development initiatives should be structured. The National Science Education Standards states that: “If reform is to be accomplished, professional development must include experiences that engage prospective and practicing teachers in active learning that builds their knowledge, understanding, and ability. The vision of science and how it is learned as described in the Standards will be nearly impossible to convey to students in schools if the teachers themselves have never experienced it” (p. 56). In other words, the current reform policies clearly recommend that teachers (or future teachers) first experience inquiry as learners, before they think about developing appropriate strategies to teach science as inquiry.

What makes this study pertinent for the development and evaluation of current educational policies is that there is little research to support these two recommendations when they are considered jointly. For instance, the notion that engaging in science
learning, through inquiry, would result in a change in teachers’ understandings about science teaching and learning has little empirical support (Hogan, 2000). Moreover, there is little research on argumentation in science involving teachers (or future teachers) as learners. The present study explores an experience that combines these two important aspects of contemporary reform: evidence-based explanation to learn science, and teachers engaging as learners in scientific inquiry. In other words, in this study, prospective teachers learn science through “exemplary” inquiry practices. Thus, this work has the potential to provide further support to (or challenge) contemporary reform recommendations, having implications particularly to how teacher education programs are evaluated and teacher certification policies.

Finally, the present study has the potential to contribute to science teacher educators’ practices. It provides a different approach to how prospective teachers engage in argumentation in the context of science learning, a process that takes place through time. Furthermore, it will try to recognize some factors that could be determinant to the nature of the process. This information would be valuable to science educators in designing science education courses as well as programs. One can identify aspects that need to be addressed in a course, which ones could be addressed initially, and which ones, being more complex, are better addressed later. For instance, if the notion that “scientific arguments should include pieces of evidence” appears to be a simple one for prospective teachers to understand, science educators can approach this issue earlier in a course/program, what are the notions underlying this simple idea, what factors are determinant to how evidence is used, and so on.

Moreover, reflection had been an important component of teacher education programs (Harvard & Dunne, 1995). However, what should *science* teachers reflect on? What experiences would be the most fruitful to these teachers’ development? The present study represents an effort to establish connections between teachers’ experiences and ideas that emerge in the context of science teacher education, and to understand how they can inform the development of strategies that are more specific and more appropriate to future science teachers.
Chapter 2
Literature Review

1 The Challenge of Defining a Constructivist Orientation

In this section, I discuss my theoretical orientation of constructivism in relation to learning and science. For many readers, it may appear at the same time ambitious yet unessential to include such a discussion in this kind of study. Although many authors have extensively discussed constructivism inside and outside of education as well as inside and outside of science for decades, there has not been much consensus or agreement on this topic. However, I believe that positioning myself within this discussion has a number of implications for my work as a science educator, both in the narrow context of this study and in the broader context of my professional life. How can I do research on learning without talking about my perspective on learning? How can I do research on science without delimiting my perspective on science? Both issues are related to my theoretical perspective, which is oriented by constructivism.

1.1 Complexities of Constructivism

It is almost commonplace to say that constructivism is a paradigm for the social sciences, in particular for education and science education. Today, it would be rare to find someone who supports the notion that an individual’s mind is an empty vessel to be filled with knowledge that is ready-made and can be acquired by a process of absorption (Phillips 1995; Osborne 1996). On the contrary, constructivists, educators, and social scientists in general tend to believe that individuals (including researchers) through their

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1 By using the term “professional life,” I risk implying that one’s professional and personal life are separate and disconnected from each other. This is not my intention. I use this term to delimit some spaces in my life that I believe are more pertinent to the study and the reader.
everyday experiences develop their own theories about the world as well as their own criteria and methods for their inquiries (Phillips 1995; Osborne 1996). Moreover, constructivists challenge the belief that knowledge can exist in dissociation from, or despite, meanings that humans construct. In other words, constructivism views all forms of knowledge as being to some extent human constructs (Phillips, 1995, p. 5).

However, to say that constructivism is the paradigm in education is misleading since to do so suggests that it represents a homogeneous set of ideas. Despite a few commonalities, the meaning of constructivism became so ambiguous that some authors recommended that educators should avoid using this term altogether (Sutton, 1996, p. 225). Other authors, like Phillips (1995), have approached the complexities of constructivism in a different way, and, instead of abandoning the term, have tried to provide a framework to understand the various forms it can take. Such a perspective is particularly useful to situate different authors and ourselves in this complex theoretical landscape without having to give up the valuable essence of the term constructivism, as we understand it.

Phillips (1995) proposed that these diverse perspectives could be described using three dimensions to represent the various forms of constructivism. The first dimension is labeled “individual psychology versus public discipline” (Phillips, 1995, p. 7). This dimension captures differences in the focus of interest of constructivists. Some constructivists are concerned with how individuals learn, focusing on how they use their cognitive apparatus to construct new knowledge, and what processes and factors are involved in such acquisition and development. Scholars involved in this type of investigation have included Piaget and Vygotsky. On the other hand, under “public discipline,” the focus shifts from understanding the processes that occur at the individual level to understanding the processes of knowledge construction that occur at the collective level. In the context of science, this would be a study of the process of

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2 Although I use the term individual level, I do not necessarily mean to imply that the individual is constructing knowledge by him/herself, as this process may involve social interaction. The point is that the interest is in understanding how individuals learn.
knowledge construction in society in general at the institutional level (universities, research institutes, companies) or in particular groups (e.g., indigenous people). Science studies have focused on this dimension of constructivism.

Phillips’ second dimension, “humans the creators versus nature the instructor”, addresses the role of people in the process of knowing and learning. In other words, to what extent is knowledge made by people, in contrast to knowledge already existing in the world, to be found or discovered by people. Here, the issue is the nature of reality and its implications for learning and scientific knowledge construction. Finally, the third dimension involves the active process of knowledge construction. Some authors describe this activity as an individual process, whereas others describe it as a collective process, involving social and political elements. Other scholars have described learning as a combination of individual and collective processes.

The questions raised through these three dimensions devised by Phillips (1995) are extremely pertinent to a significant understanding of the present study. How do people learn? How is knowledge constructed? Is there a reality out there to be discovered? Who constructs knowledge? Is it generated in individual’s minds? In my opinion, my study cannot be understood (or possibly even be approached) outside the context of the constructivist theoretical orientation that guided this research. These questions have touched my life in various ways.

As an educator, I have particular understandings of what it means to “learn” and how people learn. In fact, in these understandings was the very motivation to conduct a study like this. Moreover, these conceptions informed the way I designed the research, for instance, and in the way that the study would occur in a context that had the potential to promote learning. Finally, to make sense of what emerged from the study, i.e., its results, I used the lenses of what learning is and how people learn. As a scientist, the understandings about science and scientific knowledge that a science educator holds, directly influence their work. Putting it simply, a fundamental question that derives from

3 Brickhouse (1998, p. 112) defines science educators as scientists.
this confluence of roles (i.e., science and science educator) is What are we teaching?. In addition, the science educator is asked to reflect on what their goals of teaching science are. The answers to both questions, raised in the context of a constructivist perspective on science, can have a great impact on a study in science education in many respects. An obvious example would be how similar results could be seen as positive or negative, depending on a science educator’s perspectives on what science is and what the goals of science teaching should be. Notably, my perspectives in this regard were present throughout the process of doing this research and would be influential at various stages, not just at the very end of the research.

In this chapter, I address issues from a constructivist orientation that pertain to my work as an educator, focusing particularly on learning theories and explanations for how people learn. Then, I consider issues for science educators, addressing those apparently not connected to education, such as how scientific knowledge is constructed in the context of organized science.

As I address these aspects, the reader should keep in mind that my perspective on constructivism could also be described as socio-constructivism. Considering that this perspective – or at least this label – has been described in different ways as well as by different names (e.g., social constructionism), I first present key elements of what I call socio-constructivism. Then, I discuss major implications of such a perspective for my understandings about learning and science, focusing on major issues that emerged in these “contexts,” and contrasting the socio-constructivist perspective with non-constructivist perspectives and other constructivist perspectives. It is important to note that, although presented in this manner, these issues are related to both aspects that I address, i.e., learning and science.
1.2 Socio-Constructivism: Major Characteristics

In my opinion, the essence of my understanding of socio-constructivism rests in the notion that knowledge is always socially constructed. This statement has caused considerable polemics and resistance among scholars (e.g., Anderson, Reder, & Simon, 1997). However, unless we further discuss other important elements of socio-constructivism, as well as propose mechanisms through which knowledge is socially constructed, such a notion has limited value. This is what I intend to do in this section.

The work of Berger and Luckmann (1966) on the sociology of knowledge is essential to our current understanding of the process of the social construction of knowledge (Burr, 1995). These authors proposed that the three major processes of knowledge construction are: externalization, objectivation, and internalization. First, people ‘externalize’ ideas through artifacts or practices. For instance, someone thinks that the origin of the diversity of life can be explained through natural selection, so they write a book on the origins of species. Once these ideas are expressed, they become a body of information – or an object – with which people can interact and which can be used and processed by others in different ways. For instance, people start to use the theory of natural selection to explain phenomena in such a way that it is taken as real. Finally, some people are born when this idea is already part of their world, so it is internalized into their consciousness. For instance, since I was born after the theory of natural selection was developed to explain the origin of diversity among living beings, I have readily used the lens of natural selection through which to view diversity. By considering the processes involved in knowledge construction at the social level, one can better understand how ideas that we take to be facts, truth, and unquestionable have their origins in social practices. Moreover, it is possible to understand why we are sometimes not conscious of these social origins of knowledge, especially since we take for granted that ideas derive from an external reality that is captured by the individual rather than through social construction (Burr, 1995).
Thus, to understand the process of knowledge construction as social, many other ideas become important from a socio-constructivist perspective. Burr (1995) identifies seven important aspects of socio-constructivism, which the reader should keep in mind. First, the natural and the social world are products of social processes, that is, there are no “essences inside things or people that make them what they are;” instead, their characteristics are generated within a cultural and historical context (p. 5). Second, “our knowledge is not a direct perception of reality” (p. 6). Third, explanations are dependent on cultural and historical contexts (p. 6). Fourth, meanings are dialogically constructed through language. Thus, “language is a necessary pre-condition for thought as we know it” (p. 7). Consequently, language is understood as a form of social action since it is seen not only as an expression of ideas; but as the very action of constructing ideas is embedded in language (p. 7). Sixth, socio-constructivism rejects both the idea that social phenomena can be explained by processes that take place inside the individual (e.g., attitudes, motivations, cognitions) and that social phenomena can be explained only through social structures (e.g., economics, institutions). From the socio-constructivist point of view, “the proper focus of enquiry [is] the social practices engaged in by people, and their interactions with each other” (p. 7, my emphasis). Finally, socio-constructivists are more interested in the processes than in the structures, that is, the focus is more on how things happen than on what happens (p. 8).

1.3 Socio-Constructivism and Learning

In this section, I focus my discussion on the first axe described by Phillips (1995) considering my socio-constructivist perspective: How people learn? How does a socio-constructivist perspective reflect my understanding of learning?

One can conceive of learning science in different ways: by memorization of ‘facts’ and equations; by displaying certain behaviors like acquiring observation and classification skills; by the development of in-depth understanding of subject matter both in its concepts and practices; by participation in a community of practice, and so on. Accordingly, different theories have oriented the perspectives of science educators who
have different visions of science teaching and learning. In this section, to clarify my perspective on learning, I contrast three major theoretical orientations to learning that have prevailed among educators in the last decades (Martinez, Saudela, & Huber, 2001; Phillips & Soltis, 1985): the behaviorist/empiricist perspective; the cognitive perspective, and the situative or socio-historic perspective.

The behaviorist considers learning to be an accumulation of pieces of information, which is assessed through the display of behavior that demonstrates the ability to reproduce or copy certain actions or structures (Lave & Wenger, 1991; Martinez et al., 2001; Phillips & Soltis, 1985). In Phillips’ words, “to behaviorists, learning was a process of expanding the behavioral repertoire, not a matter of expanding the ideas in the learner’s mind” (p. 23). The learner is perceived as an empty vessel or a blank page to be filled in. The process of knowledge acquisition occurs as the learner (the one who has no knowledge) responds to stimuli from the knower (e.g., the teacher, the textbook, the computer) and is rewarded when displaying the appropriate behavior (Phillips & Soltis, 1985). Notably, this process can be easily mastered by educators, and behavior can be easily assessed, facilitating accountability. Although this perspective has been frequently criticized and considered old fashioned, it still underlies many of the practices of science education at school and in research. For instance, we tend to measure learning through pre- and post-tests, or based on certain behaviors that our students display (e.g., supporting claims with evidence), without paying much attention to what meanings underlie those behaviors.

Within the cognitivist perspective, learning involves constructing mental schemata, map, or structure which explains how the world works. This knowledge is “individually and actively constructed” through the transformation of original schemata (or structure or map) based on new experiences the person has (Martinez et al., 2001; Phillips & Soltis, 1985). Thus, within this perspective the learner is seen as an active knower who constructs meanings based on the interpretation of their experiences, a process that is influenced by prior structures that the individual holds. Martinez et al. (2001) included within this perspective “approaches from gestalt psychology,
constructivism, and processing of symbolic information” (p. 967). Importantly, cognitivists do acknowledge that human beings are by nature social; however, these theorists argue that knowledge is not always socially constructed and that the individual frequently experiences learning that is “independent of any social structure, instruction, interpersonal interaction, or group participation” (Anderson et al., 1997, p. 20).

Finally, advocates of the situative or socio-historic perspective perceive learning to be participation in a community of practice, instead of acquisition of certain structures (Lave & Wenger, 1991). Therefore, learning is defined in relation to a social context in which individuals act. It is important to note that all learning or cognition is seen as social and situated by nature, that is, there is no such thing as non-situated or non-social learning (Greeno, 1997). Knowledge cannot be located solely and completely in the individual mind; thus, learning cannot be understood by only focusing on processes that take place at the individual level (Martinez et al., 2001). It is not hard to understand how this perspective conflicts with the previously presented perspectives. First, the focus on the acquisition of structures/behaviors that is central to the definition of knowledge and the learning of behaviorists is challenged. Second, the individualistic focus of cognitivists is criticized in regard to the perception of the learning experience as a social process that cannot be dissociated from its context. One of the consequences of these conflicts is that cognitivists have accused proponents of the situative perspective of being lost in appreciating the complexity of the situation and never getting on to doing something about it” (Anderson et al., 1997, p. 20) – and for sure behaviorists would join them in this call for practicality. Nevertheless, I believe that as researchers and educators, we should not be convinced of a need to be efficient or to be practical in a certain manner. My argument throughout the study is that by principle the situative perspective is the most appropriate, and if one gets caught in the pragmatic argument, they may have illusions that learning is taking place, when it isn’t. Evidently, the situative or socio-historic perspective is much more congruous with the socio-constructivist ideas that I discussed earlier in this chapter. Thus, it should not be surprising that I adopted this perspective in the present study.
My understanding of the situative learning perspective was informed by the work of various authors. First, John Dewey (1997) provides a powerful representation of the situative nature of educational experiences, using the concepts of *situation* and *interaction*. Any experience involves *interactions* between the individual (or internal conditions) and what we usually call the physical or objective context (or external conditions), as well as between the individual and other people. All these conditions and interactions, taken together, constitute *situations*. Thus, to live in the world is understood as living in a series of situations in which interactions take place. Moreover, in accordance with Dewey’s thought, experiences should also be seen as situated in a historical process, which would influence interactions and conditions. Individuals enter experiences with certain characteristics that are determined by prior experiences. These characteristics will shape present experiences, and people will be affected by them differently depending on how they enter them. In sum, there is *continuity* to each experience, which will affect future experiences.

Although Dewey’s perspective offers interesting insights into situative learning, he sees the individual as the one who promotes change through individual inquiry, which challenges social organization (Glassman, 2001). In my opinion, this notion represents the relationship between individual and social spheres as conflictive, implying that a distinction between learning occurs in each of these spheres. In this respect, the work of Vygostsky is more consistent with my understanding of situative learning. In his view, “human inquiry is embedded within culture, which is embedded within social history” (Glassman, 2001, p. 3). Thus, learning could not be dissociated from the *social context*, and social organization would be central to promote change (Glassman, 2001; Minick, Stone, & Forman, 1993). An important aspect deriving from this idea is that Vygotsky’s understanding of the social would go beyond social interaction to include cultural, institutional, and historic aspects (Minick et al., 1993).

This Russian scholar’s work was not only important in better defining the significance of the social to learning, it also provided insights into the role of language in learning. For Vygotsky, language is understood as not only a means for the expression of
ideas, but the very tool for thought. In Vygotsky’s view, by using words, people are able to develop more sophisticated ways of thinking (1962). Again, the social nature of language is emphasized throughout his work. Some authors have argued that Vygotsky’s concern with the relationships between language and thought, in fact, derived from his conceptions of the interconnectedness between the social and psychological (Minick et al., 1993). Supporting this idea is the fact that the Russian word (riétch) that we (Americans and Brazilians at least) have translated to mean language or discourse also means conversation in Russian, implying that language is social action/interaction, not static and individually used (Bezerra, 2001). In sum, the use of the Russian word would necessarily imply dialogical (and social) interaction through language.

Furthermore, we must recognize that Vygotsky’s work does not take place in an intellectual vacuum (Minick et al., 1993). Particularly, in respect to language and discourse, the work of other Russian scholars was very influential (Bezerra, 2001; Minick et al., 1993). These authors also assumed an important role in contributing to the understanding of language and discourse in the context of situative learning. Brown and Campione (1998), for instance, refer to Bakhtin’s concept that any “understanding is dialogic in nature.” They point out that it is through the development of a voice that a knowledge base - which lies within a system of meaning, beliefs, and activity - is constructed.

Finally, a more recent contribution to the literature, which also informed my understanding of the situative perspective, came from Brown et al. (1989) and from Lave and Wenger (1991). In my opinion, Brown et al.’s work emphasized two aspects that are particularly valuable in the context of research in science education: the discipline cultures and how learning at schools should look different considering the situative perspective. These authors, who consider concepts as originating within the context of specific disciplines’ cultures, see learning as a process of enculturation. For instance, scientific concepts cannot be dissociated from the physical and social contexts in which they originate. Thus, schools should try to reproduce these cultures to a certain extent, and teachers should model their practices and discourses, permitting students to
experience such concepts as practitioners of the culture. This is particularly useful in terms of science education discipline-specific communities of practice. Lave and Wenger’s (1991) purpose in addressing situative learning is not to restrict the discussion to learning occurring in the context of school but to approach learning as a situative phenomenon that also occurs outside of school. An essential notion that emerges from their work is the definition of learning “as increasing participation in communities of practice [concerning] the whole person acting in the world.” (p. 50). Thus, learning is not understood as a process of internalization, in which learners reproduce structures or copy behaviors; instead it is a dynamic and complex social process. Notably, at least two implications of this view of learning are emphasized by these authors. First, learning is not an individual process; it is distributed among people, objects, artifacts, and other elements of the context. Second, they emphasize the negotiated character of meaning construction, involving issues of power in a broader context, which leads to reproduction and transformation. In their words,

Because of the contradictory nature of collective social practice and because learning processes are part of the working out of these contradictions in practice, social reproduction implies the renewed construction of resolutions to underlying conflicts. In this regard, it is important to note that reproduction cycles are productive as well. They leave a historical trace of artifacts – physical, linguistic, and symbolic – and of social structures, which constitute and reconstitute the practice over time. (p. 58)

In sum, all these authors complement each other in the development of a situative socio-historic understanding of learning as a complex social process that is embedded in a network of meanings and ‘realities.’

1.3.1 Authentic Science

An important notion deriving from the work in situated learning is that of authentic science. Although authentic science has been understood in multiple ways (Martin, Kass, & Brouwer, 1990) there are two major understandings of it (Putnam & Borko, 1997). On the one hand, Brown et al. have defined authentic science as “the
ordinary practices of the culture [of experts]” (p. 34). In other words, students are expected to engage in and understand science and its practices as represented in organized science. On the other hand, *authentic science* has been also identified as engaging students/learners in thinking that would be important in their everyday lives (Putnam & Borko, 1997). Although the term *authentic* was not used by Vygotsky, he emphasized the importance of bridging everyday life and science (or school) ideas, which is reflected in this second notion of authentic science. From his point of view, people, through schooling, acquire more powerful understandings of the world, but scientific ideas cannot be constructed in disconnection from everyday understandings; they are, in fact, an elaboration of them (Panofsky et al., 1990). My position on the issue of *authentic science* is that both authors’ visions are complementary. It is important that learners engage in science and learn about experts’ cultures (i.e., what organized science is like), but at the same time, they need to establish norms in their own community of learners and be able to establish a connection between science and their everyday lives (Brown, 1998). This position is directly related to my own understandings of science that are discussed in the next section.

In the present work, the situative learning perspective and the work of these various authors influenced this study as follows: the development of the course in which the study took place, the development of research questions, the design of the course, the data analysis, the structure of the narrative of the dissertation, and the discussion of results. When I thought about learning, I tried to use the lens of socio-constructivism and situated learning to examine it. In this study, my major interest was not in assessing to what extent, or demonstrating that, PTs in SCI ED 410 were able to reproduce structures, or that they could internalize science concepts and abilities to construct arguments. I wanted to better understand how PTs participate in a community of practice that was organized around certain argumentation practices. I assumed that to understand this process of participation (i.e., learning), I needed to learn about the meanings PTs constructed from their experience, not just to observe their behavior and examine the *products* of their learning.
1.4 Science and Constructivism

So far, I have discussed my perspective on learning and how it relates to socio-constructivism. In this section, I present my understandings of science and establish connections with a socio-constructivist perspective on science. As we adopt this perspective to understand how scientific knowledge is constructed, one question that has fostered intense discussion relates to the notion of reality and its role in science. Discussions in the philosophy of science, specifically debates over relativism, have focused on this question: Do scientists create knowledge, or do they discover it (Hess, 1995)?

In this respect, Hess (1995) identifies three types of constructivism: conservative constructivism, moderate (or realistic) constructivism, and radical constructivism. Hess uses a metaphor to characterize conservative constructivists. Within this perspective, social interests and cultural values are “weeds to be picked from the garden of science to make room for the flowers” (p. 35). In other words, conservative constructivists recognize the influence of the cultural and social contexts in science, but consider them as bias to be eliminated. Again, Hess’ metaphor is useful to distinguish the moderate constructivist from the conservative constructivist. Within the moderate perspective, social interest and cultural values are “the soil upon which the flowers grow” (p. 36). Through this metaphor, not only the inevitability but also the importance of socio-cultural values in knowledge construction becomes apparent. However, it is worth noting that for moderate constructivists, the explanations of the real world are still realistic: human construction and reality both contribute to framing scientific knowledge (Croissant & Restivo, 1995). Finally, radical constructivists - in accordance with Hess, a minority among constructivists – argue that social and cultural aspects are what determine the nature of scientific theories, the natural world being taken as more or less as a tabula rasa (p. 36). (Examples of radical constructivists would be scholars who

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4 The term “radical constructivism” is also commonly used in the context of educational research by authors such as Ernst von Glasersfeld. I want to emphasize that my knowledge of this line of thought is quite limited to identifying similarities and differences between Hess’s radical constructivism and von
argue that language and discourse have primacy in defining what is real, meaning that experience has a marginal role in influencing our understandings; e.g., Burr, 1995). Some authors have called such a perspective *everything is text* (Croissant & Restivo, 1995; Smith, 1999).

In various contexts, including the natural sciences and science education, the complexity of this issue has usually been overlooked, with a tendency to place scholars in opposite camps. Often what Hess (1995) called moderate constructivist is portrayed as the same as radical constructivist. These constructivists are accused of seeing science as purely *fictional*, of being relativists, and of dismissing any rational endeavor. Moreover, some authors, interestingly, have called radical constructivists social constructivists (e.g., Brush, 2000; Chinn, 1998). For instance, the *Science Wars* have involved accusations and the polarization of views on science and knowledge construction. In this war, the social constructivists argue that cultural perspectives and social interests play an important role in the construction of scientific knowledge. They claim that “truth is not objective but is relative to the individual or the culture” (Brush, 2000). But scientists see the social-constructivist perspective as a threat to scientific endeavor – calling their opponents anti-science. In their view, social constructivists equate science with any other way of knowing and with every form of knowledge that is constructed; thus, none could claim absolute validity or superiority over another. The immediate consequence would be that the credibility that scientific knowledge has enjoyed as a result of its efficiency in solving societal problems would be ignored. One of the results, for instance, would be reduced funding for scientific research. Another would be the promotion of a negative image of science as centered in a white male, western cultural perspective. Moreover, in Alan Sokal’s words, the social constructivist perspective ignores the fact “that rational Glasersfeld’s, though with some confidence. A debate between von Glaserfeld (1996) and Phillips (1996) illustrates the complexity of this matter. In short articles, Phillips (1995, 1996) appears to argue that radical constructivists regard the natural world as “non objectively real construction” (p. 20), whereas von Glaserfeld (1996) states that, from a radical constructivist perspective (i.e., his), nature and reality do inform knowledge construction, but only “negatively”, that is, showing us “what concepts, theories, and actions are not viable” (p. 19). In sum, there appear to be parallels and differences between radical constructivism in educational research and that discussed by Hess.
thought and fearless analysis of objective reality (both natural and social) are incisive tools for combating the mystifications promoted by the powerful” (Sokal, 1996, p. 6, cited in Brush, 2000). Sokal then argues that social constructivists through his criticism of science are supporting obscurantism.

As I identify moderate constructivism as a component/characteristic of the constructivist perspective, and as it becomes evident that there has been some confusion as to what these ‘constructivisms’ are, discussion of this issue becomes essential. In science studies, many authors have called our attention to such misunderstandings and to a consequent mystification of socio-constructivism. I use the term *mystification* because of the powerful image that ‘science wars’ have created in people’s minds, including those of science educators. *War*, in this case, implies a bloody conflict, with *good* and *bad* guys, which is based on *mass destruction*, that is, on the belief that only one group will win and survive. Some scholars have questioned whether there is, in fact, such a thing as science wars, or if they are just a polarized image of this *philosophical* conflict, in which socio-constructivists are portrayed as the *evil ones* to be banished from academia in general, or science education in particular (Restivo & Loughlin, 2000).

The literature in science studies may shed some light on this conflict and help science educators – as social scientists working with science – to find a place in the theoretical landscape, and thus ease the tension, if not reconcile the two warring camps: those in the natural sciences and those in the social sciences. In my opinion, two steps are particularly relevant to this process of reconciliation. First, one must understand that the socio-constructivists, who have been described as relativists, do not deny the role of nature in the construction of scientific knowledge. Second, the socio-constructivists are not attacking rationality. To address these aspects, I initially present the socio-constructivists’ ideas about the role of reality in knowledge construction, and then discuss the purpose of developing a more encompassing conceptualization of what science is as a rational endeavor.

Many socio-constructivists have discussed the notion of reality and made explicit their position in this respect. Knorr-Cetina (1993), for instance, describes the accusation
that socio-constructivists “conflate (...) the existence of the world with what we know about it” as an “epistemic fallacy” (p. 557). Thus, according to her view, every constructivist would acknowledge the pre-existence of an (unknown) material world but would argue that objects (or concepts) that are defined by science don’t have prior existence, but are created within a socio-cultural context. These objects come to existence through a series of processes defined by this context, such as “the making of distinctions, recurrent forms of interaction or reference, and the like” (p. 558). To illustrate the role of reality in this process of knowledge construction, Knorr-Cetina (1993) uses the metaphor of a mouse running from a cat: “the lesson is that we need not to assume that the mouse carries a correct representation of the enmity in its head.” In other words, the success of modern science does not necessarily imply that it has a correct representation of the material world, and thus, such success does not imply that modern science is not influenced by worldviews. Consequently, modern science is at the same time to some extent fictional as well as empirical.

Much of the criticism of socio-constructivists came from their argument that science, like all human endeavors, is a product of worldviews, or is socially constructed (Restivo & Bauchspies, 1997). Usually, science and scientific knowledge are seen as neutral and as immune to contexts of time, space, social class, gender or ethnicity. Similarly, following a Baconian perspective that prevails in our society, to be objective and rational has meant to be neutral and distanced from these contexts (Milne & Taylor, 1998). Thus, not surprisingly modern science came to be a symbol of objectivity and reason. Even social scientists, influenced by these notions, have studied modern science taking for granted that science is the most appropriate way to learn about the natural world. Accordingly, their focus has been on how science as it is works, not considering modes of inquiry alternative to modern science (Croissant & Restivo, 1995). In this Myth of Purity (Croissant & Restivo, 1995, p. 57) lies the hegemony of science (Aronowitz, 1988; Restivo & Loughlin, 2000), which is questioned when scientific facts and science are considered situational. Naturally, those who posed this challenged have
been called anti-science by many natural scientists, as if modern science and science were synonyms.

On the contrary, scholars in science studies have argued that the recognition of the socially constructed nature of science is not a threat to rationality but “an act of inquiry” (Restivo & Bauchspies, 1997, p. 398) that is extremely beneficial to knowledge growth in society and in science. Not to critically examine modern science is to take it as an absolute authority and as the sole mode of understanding nature, that is, it would be to mystify it (Croissant & Restivo, 1995; Restivo & Bauchspies, 1997; Restivo & Loughlin, 2000). In this context, a different conception of what is science emerged. Loughlin & Restivo (1997) proposed that science could be seen as “a strategy for producing defensible knowledge, grounded in shared experience rather than authority – knowledge which has a strong but tentative status as the basis for action” (cited in Restivo & Loughlin, 2000, p. 145). At the same time, this conception broadens the possibilities of what science and rationality can mean, and provides some focus on essential aspects of science for social scientists (and educators in particular).

In the present study, the participants engaged in the process of learning modern science, using the discourse, methods, and practices of this science. However, I am aware that modern science has been framed in a certain context, and is a certain way of doing science. Furthermore, I have (and had) a concern with valuing the aspects emphasized by Loughlin & Restivo, (1997). Consequently, I have taken into consideration the implications of adopting this particular scientific perspective as if it is not a neutral and/or the single form of rationality.
2 Argumentation

In the following sections, I focus on the issue of argumentation, its significance for learning and science learning, and, finally, for teacher education.

2.1 What is Argumentation?

To be engaged in argumentation is not rare in most people’s lives. We argue with our siblings, we argue with our colleagues in professional matters, we even argue with ourselves when having to make a decision. However, the fact that we are so familiar with argumentation may result in confusion as to its definition. Frequently, to argumentation theorists’ discontent, many people equate the study of argumentation to doing logic (Driver, Newton, & Osborne, 2000; vanEemeren et al., 1996). However, argumentation and logic are quite distinct. VanEemeren et al. (1996) identified elements that characterize argumentation: first, (a) “argumentation is a verbal activity, which is normally conducted in an ordinary language (such as English)” (p. 2); second, “argumentation is a social activity, which in principle is directed at other people” (p. 2); third, “argumentation is an activity of reason, which indicates that the arguer has given some thought to the subject” (p. 2); fourth, “argumentation always relates to a particular opinion, or stand point, about a specific subject. The need for argumentation arises when opinions concerning this subject differ or are supposed to differ” (p. 2), and finally, “argumentation is aimed at increasing (or decreasing) the acceptability of a controversial standpoint for the listener or reader” (p. 4). In contrast, logic arguments (also called analytic arguments) are, for instance, considered apart from the context in which they are developed (the situation, the people involved). Moreover, arguments in logic follow a standard form that eliminates different wording and incorporates logicians’ terms (vanEemeren et al., 1996).

In the literature, two major types of arguments are described: rhetorical and dialogical arguments. Dialogical arguments (also called dialectical arguments, or
collaborative arguments) could be described as a dialogue between people who hold different views (Kuhn, 1992).

In a dialogic argument, at a minimum one must recognize an opposition between two assertions – that, on the surface appearance at least, both are not correct. Evidence must then be related to each of the assertions, and, ideally, if the argument is to move toward resolution, this evidence needs to be weighed in an integrative evaluation of the relative merits of the opposing assertions. (Kuhn, 1991, p. 12)

On the other hand, rhetorical arguments (also called didactic by some authors) are described as “a connected series of statements intended to establish a position” (Andrew et al., 1993, p. 16; cited in Boulter & Gilbert, 1995, p. 90; see also Jimenez, Rodriguez, & Duschl, 2000; Kuhn, 1992). In this case, the thinking of the audience plays little role in the way the argument is structured (Boulter & Gilbert, 1995). Some authors have characterized this type of argument as “relatively simple and linear” (Boulter & Gilbert, 1995, p. 90); however, Kuhn (1991) notes that “though an argument in this sense may appear less complex cognitively, the same skills are in fact entailed in more implicit form. An assertion with accompanying justification (…) is an empty, indeed superfluous, argument unless one can conceive of the possibility of the assertion being wrong – in other words, conceive of an opposing assertion” (p. 12). In sum, although in rhetorical argumentation the arguer does not have to establish a direct dialogue with their audience, they must consider (and weigh the evidence for) other perspectives.

An important aspect that should be added to these characterizations is that arguments, particularly dialogical arguments, have typically been described in an oppositional language. Boulter and Gilbert (1995) argue that “so far (…) we have offered no model of classroom interaction which is not based on the polarization and conflict of positions” (p. 96). In their opinion, the process of argumentation also involves individuals looking for similarities, which needs to be further explored, and should be more emphasized in descriptions. Boulter and Gilbert suggest that it is important to explore other languages that do not exclude more collaborative experiences from diverse groups (such as females).
Until the 1950s, the study of argumentation was quite restricted to a classical tradition and, to some extent, to modern logic. “The attention paid to reasoning in colloquial language found expression mainly in attempts to make rhetorical and logical insights applicable to teaching, without any question of theoretical innovations” (vanEemeren et al., 1996, p. 52). One of the most popular philosophers to initiate a change in this regard was Stephen Toulmin, who studied argumentation in natural settings, and defended the notion that there were no universal norms to evaluate and construct arguments (such as logic); on the contrary, relevant aspects of arguments would vary depending on the context (e.g., everyday life situations, scholarly disciplines) (vanEemeren et al., 1996; Driver et al., 2000).

Despite recognizing some variances in argumentation from field to field, Toulmin proposed a general model or pattern to evaluate arguments (Driver et al., 2000; Russell, 1983; vanEemeren et al., 1996). The major components in Toulmin’s model are:

*Claim*: the expression of a view, conclusion, assertion, opinion;

*Data*: facts on which the claim is based, facts that support the claim;

*Warrants*: an account of how the data leads to the claim, how the data supports the claim (Driver et al., 2000; vanEemeren et al., 1996).

According to Toulmin (1988), one aspect that differentiates data and warrants is that (…) data are appealed to explicitly, warrants implicitly (p. 100, cited in vanEemeren et al., 1996, p. 140). However, the same components are closely related since “the data we cite if a claim is challenged depend on the warrants we are prepared to operate with in that field, and the warrants to which we commit ourselves are implicit in the particular steps from data to claims we are prepared to take and to admit” (Toulmin, 1988, p. 100, cited in vanEemeren et al., 1996, p. 140).

More complex arguments would include these additional components:

*Backings*: “general conditions that support the acceptability or authority of a Warrant” (Russell, 1983, p. 31), required when the warrant is not accepted” (vanEemeren et al., 1996, p. 141);
Qualifiers: conditions under which the claim is valid;

Rebuttals: conditions of exception for the validity of the claim.

Although Toulmin’s pattern of argumentation is commonly adopted for the analysis and construction of arguments, (Driver et al., 2000; Jimenez et al., 2000; Kelly, Druker, & Chen, 1998; Russell, 1983; Yerrick, 2000), some authors have pointed to limitations in such a framework (Driver et al., 2000; Duschl, Ellenbogen, and Erduran, 1997; VanEemeren et al.; 1996). VanEemeren et al. (1996), for instance, note that even Toulmin recognized that to differentiate among data and warrants can be difficult because of conflicting definitions. These authors recommend that when analyzing arguments, we “interpret data as containing factual and specific information, and warrants as general and rule-like statements, referring to the argumentation scheme that is used (p. 159). Driver et al. (2000) noted that, although it may seem contradictory, “Toulmin’s scheme presents argumentation in a decontextualized way” (p. 294). In light of these authors’ views, the philosophers’ model does not take into consideration “interactional aspects of argument” or the influences of the “linguistic and situational contexts in which the specific argument is embedded” (e.g., meanings could be different in different contexts, warrants may be implicit, non-verbal communication can be used, such as gestures). Finally, following the same line of argumentation used by Driver et al., Duschl et al. (1997) argue that Toulmin’s pattern is not useful for analyzing dynamic interactions that take place in a classroom during small group discussion. In other words, the focus on evidence and premises would contribute to the analysis of rhetorical arguments, but it would not be the most appropriate means to understand dialogical arguments.

As we embrace the notion that argumentation is contextualized, as well as other characteristics of argumentation discussed at the beginning of this section, and in the critiques presented later, the concept of argumentation becomes more complex. As noted before, argumentation is no longer defined solely on the basis of what it is but also by what it does. Thus, “to answer the question, ‘What is argument?’ entails asking a number of others: What does argument do? Who does it? With or to whom? Where and why? Each of these questions links an understanding of argument not to the realm of the
abstract and immutable but to the social, interactional world, or more precisely, worlds” (Costello & Mitchell, 1995, pp. 1-2).

2.2 Thinking as Argument: Learning and Argumentation

When Toulmin published his book The Uses of Argument in 1958, it had little impact on psychology research (Kuhn, 1991). In the late 1980s, however, some psychologists proposed that thinking could be seen as argument. “(...) much of the thinking we do, certainly about issues that are important to us, involves silently arguing with ourselves – formulating and weighting the arguments for and against a course of action, a point of view, or a solution to a problem” (Kuhn, 1991, p. 2). Although other kinds of thinking exist, “thinking as argument is implicated in all of the beliefs people hold, the judgments they make, and the conclusions they come to (...). Hence, it is at the heart of what we should be interested in and concerned about in examining people’s thinking” (Kuhn, 1991, p. 3).

The perspective that emerged from this new notion of thinking generated questions about why people hold certain beliefs and reach certain conclusions, whether they contemplate alternative ideas, if they think about the way they reason, and so on (Kuhn, 1991). Moreover, everyday thinking (or ordinary thinking in general), despite being “open-ended, ill-structured and deeply embedded in a rich, complex knowledge base” could be explored using this framework (Kuhn, 1992, p. 156). It would be possible to learn about how people think by seeing how (and if) people engage in processes such a theory revision, evidence generation, and evidence interpretation (Kuhn, 1993).

The implications of this new perspective for argumentation are twofold. First, argumentation and learning become practically interdependent. If the idea that people think (makes sense of their reality) through argumentation is taken seriously, it implies that people construct meaning through argumentation. If learning is taken to be the same as meaning making, it implies that learning and some kind of argumentation are always related. In this context, argumentation is not considered just a vehicle to convey an opinion anymore; it is an integral part of the very thinking process (Kuhn, 1991, 1993;
Kuhn, Amsel, & O'Loughlin, 1988). In other words, knowledge construction implies argumentation.

Second, Kuhn et al. (1988; Kuhn, 1993) argue that there are many parallels between the way people think in their everyday lives and the way scientists think. Both are forms of human thinking that can be seen as argument. Thus, thinking like scientists not only is not that foreign to students’ experiences but can also contribute to a better understanding of their own ways of reasoning and understanding the world (Kuhn, 1993).

2.2.1 Learning, Argumentation, and Science Education

If taken together, the notions of argumentation theory, thinking as argument, and situated learning imply a major goal for science education: the context of science classrooms must involve argumentation to result in meaningful learning. Underlying this major goal are two assumptions that need further exploration. First, we take for granted that the authentic context of science involves argumentation. In other words, we assume that scientists construct knowledge through argumentation. Second, we take for granted that, by engaging in argumentation, people (and, in particular, students) learn. In this section, I discuss these two assumptions.

Argumentation in the Context of Science

People can have very different answers to the question How do scientists construct scientific knowledge? In fact, this question could be phrased quite differently, depending on the perspective one adopts. The origins of such perspectives can be traced back to the history of modern science to better understand their assumptions. The discussion that follows is informed by studies in The History and Philosophy of Science.

As modern science emerged as a discipline in the seventeenth century, a realist like Francis Bacon would probably ask, How do scientists discover the reality? In accordance with a realism perspective, there is an external fixed reality and only through the senses can scientists access such reality. In other words, scientific knowledge can be
generated and legitimated only through the use of observation and experimentation. There are no other ways to learn about the natural world. Moreover, inductivism is seen as the appropriate approach in the construction of scientific knowledge. One should start from what senses capture (that is, observation), build particular claims, then progress to middle axiom, then to experimentation and, finally, to general axioms (Chalmers, 1982; Milne & Taylor, 1998).

Later on, when philosophers started to study science, new notions about the nature of scientific knowledge and scientific practices emerged. For instance, falsificationists, like Karl Popper, would probably ask a similar question to that of realists. They, too, have a positivist perspective on reality. Moreover, they would also emphasize that experiments and observations would be determinant to establish the quality of scientific knowledge. However, they introduced two new essential dimensions in the notion of what science is and how it is constructed. They argued that reality could never be completely understood; what scientists do is to create progressively better explanations of reality, that is, explanations that would be closer to the reality. Scientists would use evidence from observations and experiments to test (or falsify) explanations that did not conform to the reality (Chalmers, 1982; Lakatos, 1974). In sum, although falsificationism has many similarities with realism, it implicitly considers argumentation to be part of scientific knowledge construction, recognizing that scientific knowledge is based on explanations (or theories) that scientists elaborate.

Lakatos (1974) embraced the notion of competing theories but recognized that particular experiments and isolated observations would not necessarily result in the discarding of a theory. According to Lakatos, robust theories have a belt of protection and would be discarded only if a better theory (that is, an explanatory framework) could substitute it. In other words, in the construction of scientific explanations, arguments compete and only a more robust argument can substitute for another, not isolated pieces of evidence. In sum, Lakatos described science in a way that shifted the focus from evidence (derived from experiments and observations) to explanations (arguments): scientists are not engaged in collecting data to support/challenge theories; they are
engaged in comparing competing explanations (which are constructed using empirical evidence).

Although Lakatos’ perspective presents argumentation as the essence of scientific knowledge construction, it fails to acknowledge important aspects of science that were discussed in the work of Thomas Kuhn. Kuhn, using historical cases in scientific research, argued that multiple interpretations of the natural world exist, even among scientists. In fact, to use the term interpretation would not be accurate. Kuhn, saw the existence of multiple realities that are socially constructed, incommensurable realities. From that point of view, argumentation acquires a complexity that was overlooked by Lakatos: argumentation in science is also dependent on contexts and perspectives, (i.e., it also takes place in a social context, has its purposes and interests, has participants with different roles, etc).

Informed by these new notions of how scientific knowledge is constructed, one looks at scientific practices in a different way. “Science is a social practice and scientific knowledge the product of a community” (Driver et al., 2000). For instance, papers are not published in journals before they have been evaluated and criticized by other peers; this knowledge is not legitimized before the community recognizes it.

**Argumentation in the Science Classroom**

Considering the perspectives discussed above, one may be convinced that argumentation is essential to science culture and to the process of scientific knowledge construction. Does that mean, however, that argumentation can provide an appropriate context for the establishment of authentic science and conceptual development in school science? In this section, I discuss empirical studies that support this notion.

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5 It is worth remembering that Lakatos was a passionate critic of Kuhn’s ideas. For instance, he said, referring to Kuhn, that “fashionable ‘sociologists of knowledge’ - or ‘psychologists of knowledge - tend to explain positions in purely social or psychological terms when, as a matter of fact, they are determined by rationality principles” (Lakatos, p.174).
Argumentation can be related to learners’ understandings of science concepts in two ways. First, it has the potential to make thinking transparent (e.g., Bell & Linn, 2000), evidencing limitations in students’ understandings. Second, after engaging in argumentation, learners, in some cases, demonstrate that they have a better understanding of scientific concepts, and become more articulate in using such concepts in diverse situations.

The first aspect of learners’ understanding mentioned above, making thinking visible, was explored in some studies. In a work on argumentation in genetics, high school students were asked to advise a farmer that they wanted to eliminate chickens with a strange color of feather (Jimenez et al., 2000). After analyzing the data, the authors noted that “even those students who sustained the heredity hypothesis viewed the color change as individual (mutation) rather than population change” (p. 782). Jimenez et al. attribute this thinking to limited understandings about natural selection, probabilistic reasoning, and the abstraction of the heredity model.

Another study that had similar results involved prospective science teachers in a methods course. In this case, the participants were asked to solve a problem involving evolutionary biology, i.e., explain the death of many finches and the survival of a few in 1976 on one of the Galapagos Islands (Zembal-Saul et al., 2001). Besides discussing the problem with their peers, the participants had to construct a written argument and present it to their colleagues. In particular, the evidence that participants used to support their claims reflected limitations in their conceptions about natural selection. For instance, one of the pairs presented the same difficulty in understanding the concept of population shift. Although their claims could indicate that they understood and used natural selection theory to build their explanations, to support these claims, the participants chose scatter plots instead of frequency graphs and used field notes showing how a single individual changed its behavior through time.

Although one could argue that simply eliciting alternative conceptions is not enough to change people’s conceptions, I believe that this is an important step in supporting learning. This is a potential vehicle for students to become dissatisfied with
their knowledge (e.g., Hewson, Beeth, & Thorley, 1998). In accordance with the conceptual change model, for learning to occur, the learners have to recognize limitations in their understandings. This is described as a first phase in the process of learning. However, I argue that the limitations that become apparent in students’ discourse or class work (as they propose solutions to problems, support them with evidence, and interact with their peers) would not be as clear if the task did not involve argumentation.

There is also some evidence that argumentation results in a robust understanding of scientific concepts. Yerrick (2000) worked with lower track high school students in a physics course, who engaged in investigations in which they “[gathered] evidence and [proposed] explanations for everyday events” (p. 815). Yerrick conducted interviews at the beginning and end of the course to assess the participants’ abilities to build explanations related to electricity and to apply their knowledge to two different scenarios. In the first interview, most of the students did not provide warrants in their responses. At this stage, the students tended to respond to the questions in two ways. They would say that they did not know the answer or they would give an answer, state that it was based on something they have experienced and that would prove they were right. Yerrick also describes situations in which the students responded that they would ask ‘an expert’ because they did not know anything that could be useful to solve the problem that was presented to them. In the second interview, after engaging in argumentation, the students responded to the questions in a different manner. Students were able to propose solutions to the problem and were able to suggest ways to ‘test’ their ideas.

These results strongly support the notion that argumentation can lead to learning. In this case, the students were able to use scientific concepts to solve everyday problems. Moreover, they used these concepts in a dynamic way, demonstrating understanding of how these concepts were constructed (and could be further supported through experiments, for instance).

Another question that I address in this section is whether science argumentation has the potential to contribute to a better understanding of science and scientists’ practices, in particular, the practices of argumentation in science. Driver et al. (2000)
describe the results of an interesting study by Kuhn et al. (1997) on informal argumentation. Participants (adults and adolescents) were asked to build arguments related to the same topic (capital punishment). Before presenting their arguments, however, some of them engaged in discussions of the same topic with another participant. In these cases, the arguments were much more robust. For instance, these arguments encompassed a broader range of evidence, and they explicitly explored more than one side of the issue (specially among adults). These results suggest that by engaging in informal argumentation practices, the participants developed better abilities to build arguments. In another study, the students added new components (such as warrants, and evidence) as they engaged in the process of building arguments about light, and interacted with peers (Bell & Linn, 2000). Similar results were observed by Yerrick (2000) in his research with lower track students.

Besides enhancing participants’ abilities to argue, there is some evidence that argumentation also has the potential to help learners develop better understandings of the nature of science. Bell and Linn (2000) did a pre-assessment and a post assessment of 7th and 8th graders’ understandings of the nature of science before and after they built evidence-based arguments about how light travels. A comparison of the assessments indicated that “students at the post-test displayed a greater propensity to believe in a dynamic nature of science than did those at the pre-test” (p. 814).

**Issues in the Process of Argumentation**

Despite its potential to lead to science learning, engaging in argumentation frequently poses a series of challenges to learners. In this section, I discuss some of the difficulties identified through empirical studies: the tendency not to take into consideration alternative explanations, lack of evidence to support conclusions, and lack of justification relating conclusions to evidence. I believe that the recognition of such problems has the potential not only to help us better understand the process of argumentation but also to shed light on some of the limitations of the strategies we adopt in the classroom, as well as on the theoretical framework that informs such practices.
The first issue discussed in this section is the tendency to ignore alternative explanations, which can compromise argumentation to a great extent. Kunh (1991, 1993) points out that being able to conceive of alternative explanations is a fundamental component of argumentation. Evaluation of one’s explanation would depend on “recognizing that one could be wrong” (1993, p. 114). In an extensive study on informal argumentation involving people of different ages and backgrounds, Kuhn (1991, 1993) found that most of the participants were able to consider alternative theories. However, most of them generated such theories upon the request of the researcher, and did not provide any evidence to support them. In these conditions, such alternative theories cannot be considered actual counter arguments to initial explanations, and thus have limited significance.

In another study involving 7th and 8th grade science students who were learning about light, Bell and Linn (2000) had similar results. Although students were presented with two opposing hypotheses, the authors reported that the students rarely included backings to the warrants in their arguments. Bell and Linn argued that backings are included in arguments only as warrants are called into question, and the lack of backing was probably related to the fact that the students were unable to pose counter arguments to their explanations. In other words, despite being provided with two alternative explanations, students aligned with one of them and did not consider the other as possible.

Another problem that has been identified as one engages in argumentation is the lack of evidence. Prior studies indicate that it is quite common that people do not provide genuine evidence to support their claims (Kelly et al., 1998; Kuhn, 1991, 1993; Yerrick, 2000), and thus have difficulty distinguishing theory (claims) from evidence (Kuhn, 1993).

Kuhn (1994), in her study of informal argumentation, provides good examples of how people can have trouble supporting their claims with evidence. Most of the participants did not include evidence in their arguments or did so very rarely. Kuhn identified various kinds of circumstances in which the lack of evidence occurred.
Sometimes the subject considered evidence unnecessary. For instance, one individual explained how she would convince someone else that her ideas were right as the kind of evidence she would provide: “I would not try to give any evidence. I only ... when it comes to kids, I work by my good instinct, and I would say there are sometimes parents who are totally tuned into their children will know more than the professional” (p. 82).

In the same study, another condition in which evidence was not provided involved the lack of understanding of what evidence is. When asked to provide evidence to support their theory to explain the phenomena (or claim), these individuals simply restated their claims. However, the most common scenario involved subjects using the very phenomenon that they needed to explain as evidence to support their claims. For instance, one subject argued that the cause for poor grades at school was malnutrition, and when asked to provide evidence, stated: “[the evidence is] the grades they get in school show ... that they are lacking something in their body” (Kuhn, 1991, p. 87).

Another important aspect that emerged from Kuhn’s research is the notion that people respond to and interpret evidence in quite complex ways. Kuhn (1991) also had explored the complexity of responses that people provide when confronted with evidence as they try to make sense of phenomena. An interesting response is to interpret any piece of evidence as illustrative or confirmatory of one’s theory. Kuhn notes that,

Subjects typically assimilated both kinds of evidence to their theories. ‘This pretty much goes along with my own view,’ was the prototypical response. Subjects expressed high certainty reading their evaluations of this evidence (just as they did about their theories). If evidence is simply assimilated to a theory, any ability to evaluate its bearing on the theory is, of course, lost. (p. 326)

Other authors explored the issue of peoples’ responses to evidence more systematically. Zeidler (1997) described types of reasoning that could result in fallacious arguments, some of the most common being inadequate sampling of evidence and hasty conclusions or generalizations. One example of such practices would be to “seek too little information to warrant a firm conclusion or to achieve credibility in the transfer of particular instances to other settings” (p. 491). Chinn and Brewer (1998) identified eight
possible responses to anomalous data: ignoring data, rejecting the data, professing uncertainty about the validity of the data, excluding the data from the domain of the current theory, holding the data in abeyance, reinterpreting the data and changing data, accepting the data and making peripheral changes to the current theory, and accepting the data and changing theories. These authors explicitly say that scientists have all these kinds of responses to data as well as learners. In sum, these studies indicate that there is not a single and consistent way to respond to evidence; on the contrary, people understand (and consequently use) evidence in very different ways.

Finally, the third major limitation that frequently occurs when people engage in argumentation is the lack of justification connecting claims to evidence. This pattern has been documented in the literature. High school students investigating a problem on evolutionary biology tended not to provide justifications for the relevance of evidence (Sandoval & Reiser, 1997). Kelly et al. (1998) had similar findings in a study involving problem-solving assessment on electricity. As noted earlier, Yerrik (2000) reported that before receiving instruction specifically designed to develop argumentation skills, lower track high school students provided many facts that were dissociated from warrants in their responses to problems.

Jimenez et al. (2000) studied the discourse of Spanish 9th graders engaging in argumentation about genetics. The authors observed that the two problems discussed above, lack of evidence and lack of justification, were sometimes associated with each other. Students in small groups were given a problem to solve (explain how a farmer could avoid having chickens with yellow feathers). This activity was followed by a whole class debate in which students presented their conclusions and had to explain their reasoning. The analysis indicated that claims were the most preponderant component in both the small group and whole class discussions. For instance, in one of the groups, two-thirds of the components were claims. This kind of result is considered an indication that “most claims were offered without any relation to other elements [such as evidence and warrant]” (Jimenez et al., 2000, p. 780).
Aspects Influencing Argumentation in Science Learning

Identifying problems and challenges in learners’ experiences as they engage in argumentation is important. However, this is not enough if the goal is to support students (and teachers) in learning science through argumentation. One needs to better understand the complex process that is taking place in the classroom, trying to identify what may be influencing learners’ experiences. I address this issue in this section. The discussion is organized around three levels of experience that may influence argumentation in the context of school science: the classroom context, epistemological aspects, and ontological aspects.

Immediate Classroom Context

Nature of the task

The nature of the task, i.e., what students are expected to do, how the teacher/instructor structures the activities, how he/she supports the students, etc., appears to have a great deal of influence on students’ experiences with argumentation. This has received considerable attention in studies of argumentation in the context of science classrooms. Various studies have indicated that the nature of the task can be very influential in the process of argumentation, in many respects.

Kelly et al. (1998), for instance, studied arguments that students generated during peer interactions as they engaged in performance assessments on electric circuits. The authors were mainly interested in the conditions under which, and how students generated warranted arguments, connecting their claims to evidence using justifications. However, interesting aspects about the nature of the evidence that was used emerged from this study. For instance, the kinds of evidence used in warranted arguments seemed to be related to the kind of task in which students were involved. Empirical arguments occurred more frequently as the students had to formalize their explanation, whereas hypothetical arguments occurred more frequently as they try to solve the problems. It appears that these students were forced to refer to empirical data as they
formalized/articulated their explanations. Prospective teachers also constructed different arguments, depending on the task they were involved in (Zembal-Saul et al., 2001).

Moreover, Kelly et al. (1998) noted that the ability to solve the problems involved in the task was not related to the use of warranted argument. Students who rarely used justifications in their arguments were successful in accomplishing the task. Sandoval and Reiser (1997) noted in the results of their study that, in the software environment used by the participants, data were frequently self-explanatory, making justification redundant. In other words, the nature of the task did not require learners to include justifications (warrants) in their arguments.

Jimenez et al. (2000) argue that the key to robust arguments is to create a context that is appropriate to the development of justification skills. In such a classroom context, “… students were [are] asked to solve authentic problems [that were related to their personal knowledge], to compare the solutions given by different groups, and to justify their choices” (p. 759). Moreover, the teacher should try to “ask questions that have a wide range of possible answers, or ask for a student’s opinion or real-life experience …” (p. 764).

A similar experience with low-track high school students also resulted in more sophisticated arguments that included justification (Yerrick, 2000). In this case, the students investigated questions that they posed, and designed and engaged in a series of experiments to generate evidence to build explanations.

Bell and Linn (2000) also had most of their participants (70%) include justifications in their explanations, instead of providing pure descriptions. In this case, students were given two theories that explained light behavior. The students were asked to analyze evidence and make a decision as to which theory was better supported by evidence. They were explicitly asked to rate each piece of evidence in terms of how it supported their explanation, as well as to provide a justification.

The findings of these studies indicate that it is essential to design tasks that demand that students use justifications, which can be done at different levels. First, in the
more restricted sense, the teacher can require that students include justification as part of the task (Bell & Linn, 2000; Jimenez et al., 2000). Second, attention to the teacher’s discourse would be fundamental to make the use of justification an integral part of classroom practices (Sandoval, Daniszewski, Spillane, & Reiser, 1999; Tabak & Reiser, 1999). Finally, complex contexts/tasks in which justification is essential to argument construction are fundamental to the development of argumentation skills.

Interaction with Peers

Since we consider knowledge as being socially constructed, it is expected that the nature of social interactions would affect the process of knowledge construction through argumentation. In fact, this aspect has received some attention in the science education literature on argumentation, and the results of some studies seem to support this notion.

Richmond and Striley (1996) studied the discourse of six groups of four students in tenth grade who were engaged in an investigation on cholera epidemics. The students were expected to plan, execute, and interpret experiments that they designed. The authors noted that the roles assumed by group members were determinant in the process of developing meaningful understandings. Particularly, the leader in a group could greatly influence the dynamics of interactions. These authors characterize an “alienating leader” as someone who is sure that their explanation is the right one, who is not interested in hearing what others have to say, and who imposes their ideas on others. Richmond and Striley (1996) noted that “the leader … not only controlled the ways group members were able to participate in the work but also shaped the definition of the work to be done.” As a result, arguments in groups with alienating leaders were inferior, and the process of building these was just a procedural one.

In another study by Alexopoulou and Driver (1996), these researchers measured changes in explanations and reasoning about problems in physics, and tried to relate such changes to group discussion dynamics. As in Richmond and Striley’s study, students in groups that collaborated more and did not engage in a competitive process developed better understanding of the problem. Furthermore, the results seem to indicate that in
smaller groups (in this case, pairs), usually “preexisting attitudes and goals” were more determinant to “discussion processes and learning outcomes” (p. 1109), whereas in larger groups, conflicting perspectives tended to be resolved in more productive ways both in terms of understandings and argumentation abilities. Similar results were obtained in studies involving high school and college students constructing arguments using the theory of natural selection. High school students were able to construct more complete and detailed explanations during whole group interactions, in contrast with pair discussions (Tabak & Reiser, 1997). In a pilot study involving prospective science teachers engaged in a similar task, ideas that did not emerge in the context of pair work surfaced during peer review/whole class presentation (Zembal-Saul et al., 2001). In this case, during a whole class discussion, a significant episode of collective evaluation of evidence occurred, followed by an effort to generate evidence that would be more appropriate to solve the problem. In the same line of evidence, Bell and Linn (2000) reported that, initially, a few students saw the need for backings to their arguments. It was only during a classroom debate that backings became the focus of discussion (p. 809).

Kelly et al. (1998) created a taxonomy of the circumstances and frequency with which warrants were provided by students engaged in a problem-solving activity on electricity. In most of the cases, warrants were given in response to a question, to claims (both statements and challenges), or to data (both unproblematic and anomalous). Although the authors did not argue for a causal relationship between these aspects, it is interesting that warranted arguments occurred in such circumstances of social interaction, and rarely occurred as unsolicited.

**Epistemological Context**

Various authors have argued that, for instance, being able to understand what counts as good evidence is considerably difficult, considering that these are context dependent criteria (Driver et al., 2000; Zeidler, 1997; vanEemeren et al., 1996). The context that these authors are referring to is not solely the classroom context but a
discipline that would determine what is appropriate argumentation (Goggin, 1995). Thus, one could expect that elements of learners’ notions about the epistemological aspects of science would influence their understandings of argumentation in the context of science learning. Unfortunately, many of these aspects have not been addressed in the science education literature on argumentation.

**Prior Knowledge/Educational Background**

Intuitively, it seems reasonable to say that those who have more background in a certain field would be able to generate more robust arguments if the issue was related to this area. They would have a better understanding of the key concepts of the discipline, as well as be more familiar with the norms and theories that inform argumentation in the specific field. There is some evidence to support this notion in the field of informal argumentation.

Kuhn (1991) proposes that “subjects are most likely to generate an alternative theory for the topic for which they are most likely to have personal knowledge (…) and least likely to do so for the topic for which they are least likely to have personal knowledge” (…) (p. 112). Kuhn’s recommendation is based on a comparison of participants with different educational backgrounds and ages.

The findings of Kuhn (1991) appear to indicate that the complexity of causal theories in informal argumentation was related to factors such as level of education (the college group showed more ability to build complex causal theories than the non college group), and, again, how familiar participants were with the context of the problem.

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6 There is some research on the nature of teachers’ discourse and its relationship with knowledge in the discipline, but the focus of this research was on the perspective of the learner or something that is closer to that role, not the teachers. The rationale for my focus is that the purpose for arguing as a teacher is quite different from the purpose of arguing as a student.
Understandings of the Nature of Science

Notions about the nature of science have been recognized as decisive for the way in which students understand the practices of science (including school science) (Hogan, 2000; Lederman, 1992; Rudolph & Stewart, 1998). Moreover, one of the lessons we have learned from the philosophy and sociology of science is that our understandings of the nature of science shape our understandings of the role of argumentation in the construction of scientific knowledge. Thus, it would be natural to expect this aspect to influence the process of argumentation (and vice-versa, as discussed previously). However, there is little empirical evidence to support such an assumption.

Bell and Linn (2000) addressed this issue in their investigation on how students engage in argumentation to explain how light travels. These researchers used questionnaires to assess participants’ notions about NOS before and after the experience. Their results indicate that there is a close connection between notions about the nature of science and the way students engaged in scientific argumentation. “Students who respect that science is dynamically changing and involves the construction of arguments also personally engage in the construction of arguments. Students who dispute the assertion that the science principles in textbooks will always be true tend to restructure and add to their knowledge as they come to understand how far light goes” (p. 813). Moreover, “Students with a more sophisticated sense of scientific understanding as dynamic theorized more in their arguments by including more unique warrants and conceptual frames (...). Students who explored the interpretation of evidence from different conceptual frames within their SenseMaker argument have a more dynamic view of science” (p. 810).

Understandings of the Nature of Learning and Science Learning

Are our notions about science restricted to our ideas about science in academia and about what scientists do? Hogan (2000) proposes that the nature of science should be defined as having two components: distal and proximal. Understandings of the distal nature of science would refer to the science that takes place in laboratories, universities,
and research centers, whereas understandings about the proximal nature of science are “frameworks about science in terms of their own [individuals’] context of science learning in addition to or instead of (…) explicit knowledge of the enterprise of professional science” (p. 54). This construct is very useful for thinking about other aspects that may influence learners’ experiences with argumentation in science. This approach includes understandings of both epistemological processes (learning) and knowledge (what is to know) within science and outside of science. Hogan (2000) presents empirical evidence that supports the existence of a close relationship between domain-specific epistemologies and learning strategies, as well as with the “metacognition of scientific meaning-making.” For instance, in a study by Ryan (1984), “students with a dualistic epistemology who see knowledge in terms of single right or wrong answers are satisfied that they have learned something when they can recall information, whereas those with a more relativistic epistemology, who see knowledge as complex and relative to theoretical frameworks, are satisfied when they can apply information to a new situation” (Hogan, 2000, p. 58).

Considering that evidence, it appears that proximal notions about the nature of science would also influence learners’ experiences in engaging in argumentation in the context of school science. Kuhn (1991, 1993) explored this issue in informal argumentation, although this aspect appears to have been overlooked in studies on argumentation in the science classroom. She noted that “epistemological naivete may be a critical factor in accounting for the limited argumentative reasoning ability that people display. Without an epistemological understanding of their value, the incentive to develop and practice the skills of argument is likely to be lacking (….) The student who says (…) ‘You can’t prove an opinion to be wrong because an opinion is something somebody holds for themselves,’ lacks any basis for judging the strength of an argument beyond its power to persuade. Such students can only appreciate science in a limited way and are particularly unlikely to in their own lives” (Kuhn, 1993, p. 334).
Ontological Aspects

Much more is involved in how people engage in school science than just the way they come to know about things (and their notions of such processes). An important aspect of the way people learn (and do) science at school is related to who they are. There is an extensive literature showing that being is extremely important in framing science education experiences. Experiences outside of school related to gender (Brickhouse, 1998), social class (Barton, 1998, 2000), and ethnicity (Allen & Crawley, 1998; Kawagley, Norris-Tull, & Norris-Tull, 1998) – all interrelated – will be determinant as the learner enters (and lives) in the school science culture.

Little is known about how these experiences could influence the way learners engage in argumentation, but to deny the existence of such a relationship would contradict the very social constructivist perspective of this study. The only study that I am aware of that somehow considers this issue in the context of argumentation in science learning is Mortimer’s (1998). This author notes that in a science classroom that investigated the nature of matter, there was “a movement from multivoiceness to univocality”, from “internally persuasive to authoritative” discourse, from “the everyday voice represented by the student” to the “scientific voice represented by the teacher.” This dynamic is established by a clear notion of what Mortimer calls “ontological obstacles in the construction of scientific meanings in the classroom”: only the teacher’s being is valued, only the scientific being (in a very restrict sense) is recognized in the context. However, nothing is said about how the learner experiences such a dynamic. Moreover, we don’t know if in a context other than this classroom, argumentation would be less oppressive to learners’ being.

2.3 Teachers and Argumentation in School Science

If we are to make argumentation part of school science, we need to develop strategies and tools to support students in it. Teachers need to be prepared and participate in the development of such strategies and tools. “The success of instructional strategies
is contingent on the adequate education of preservice and inservice teachers in critical thinking and reasoning skills” (Zeidler, 1997, p. 484). But how can we support teachers?

The research on argumentation in school science has mainly focused on two kinds of experiences: the nature of the discourse of K-12 students engaging in science learning (Bell & Linn, 2000; Duschl et al., 1997; Jimenez et al., 2000; Kelly et al., 1998) and the nature of the discourse of science teachers as they teach science (Russell, 1983; Ogborn, Kress, Martins, & McGillicuddy, 1996). These studies, interestingly, have focused more on dialogical arguments when working with learners and more rhetorical arguments when working with teachers. Studies with adults engaged in argumentation that did not involve teaching were related to informal contexts (Kuhn, 1991, 1993; Kuhn et al., 1988) or to disciplines other than science (Marttunen, 1994; Marttunen & Laurinen, 2001; Ravenscroft, 2000), frequently the teaching of argumentation per se. Considering the scope of these studies, it appears that little is known about teachers’ understandings of and experiences with argumentation in the context of science learning.

Zeidler (1997) argues that “[…] we will undoubtedly fail to realize our goal of scientific literacy if we simply teach teachers about this practice, rather than involving them in the practice of constructive argumentation” (p. 485). In other words, it is essential to involve teachers in argumentation as learners before they engage their students in argumentation. In the context of the literature gap just cited, we interpret this statement in a particular way. Why would it be important for teachers to engage as learners in argumentation first, if, as researchers we just want to better understand teachers’ conceptions about argumentation? We need to do so for two main reasons: argumentation does not exist outside its context – it is situated – and the teacher is an active subject.’ This notion of argumentation occurs in a complex context, which includes the school as a dynamic social institution, as well as the teacher as a professional and as a person. Teachers should be introduced to argumentation in science learning in such a way that it becomes part of the constellation of ideas he/she holds. The teacher will be the one who will make meaning of the experiences with argumentation in the context of other experiences. Within this perspective, teachers must engage in
argumentation as learners first. This was the purpose of this study, to learn about prospective teachers’ experiences with argumentation in the context of science learning.
Chapter 3
Context: The SCIED 410 Course

1 Introduction

In this chapter, I intend to provide a description of “Technology Tools for Supporting Scientific Inquiry” (SCIED 410), the course in which the present research took place. I recognize that in the present study, the context - in particular, the instructional context – influenced how participants perceived their experiences, thus, this aspect will be addressed with a great deal of detail (in this chapter and in Appendixes A, B and C). I will first discuss the rationale that guided the design of the course at two levels: current ideas in science education and current ideas in teacher education. The reader must be aware that, since the course is part of a secondary science teacher program, the rationale for designing this specific course cannot be dissociated from the design of the program as a whole. In the second part of the chapter, I will provide a general description of the course, establishing connections between each element/activity of the course and the rational previously described. Then, I will describe in detail the fundamental aspects of the course, considering the goals of the present study: instructors’/designers’ view of argumentation. Finally, I will briefly describe the general dynamics of the class. I conclude the chapter with final remarks on the significance of this detailed description to the context of the course from an instructors’ perspective, considering the researcher’s understanding of the notion of context.
2 Science as Exploration versus Science as Argumentation

Despite the importance of scientific inquiry in the context of science education, like many fundamental ideas in education, ‘scientific inquiry’ has acquired multiple meanings and in this process it is losing much of its significance; hence, the need to make clear the meaning of scientific inquiry in the context of reform (Bybee, 2000). Mainly at the elementary level, science teachers too often equate “scientific inquiry” with “hands-on activities” used to motivate children to learn science (Abell, Anderson, & Chezem, 2000; Wheeler, 2000). At the secondary level, on the other hand, science has been portrayed as a collection of facts or “stable truths to be verified” (Alberts, 2000; Bybee, 2000). These understandings are limiting in the sense that they overlook the complexities of reform-oriented understandings of scientific inquiry that could be particularly valuable to the learner.

Two elements of scientific inquiry for science learners have been emphasized in the National Science Education Standards (National Research Council, 1996): abilities to do scientific inquiry and understandings about science and scientific inquiry. Doing scientific inquiry involves engaging in scientifically oriented questions, giving priority to evidence in responding to questions, formulating explanations from evidence, connecting explanations to scientific knowledge and communicating and justifying explanations (National Research Council, 2000, p. 29). ‘Doing science’ at school through these activities represents a shift in the focus of teaching: that is, less emphasis on “science as exploration and experiment” (or hands-on activities), and increasing emphasis on “science as argument and explanation” (or minds-on activities) (Abell et al., 2000; Kuhn, 1993; National Research Council, 1996).

The notion that learning science also means learning a way of thinking about nature underlies the other major dimension of scientific inquiry for learners, that is, that they should develop understandings about scientific inquiry. In other words, scientific inquiry from the reform-oriented perspective implies that through school science, students should learn how to “engage in a dialogue with the material world” (Minstrell &
van Zee, 2000; Wheeler, 2000). Moreover, in order to understand how scientific knowledge is constructed, it is not enough to understand scientists’ practices. Rather, it is fundamental that science is understood in a cultural and social context (Abd-El-Khalick & Lederman, 2000). Science educators have called this broader construct ‘nature of science’ (NOS). There is still intense controversy around a definition of NOS. However, some authors have proposed “common places” of NOS (using the language of Helms, 1999) that must be addressed in science classrooms. Lederman (2000) summarizes these aspects in the following list: (1) scientific knowledge is tentative; (2) scientific knowledge is partially a product of observation and inference; (3) scientific knowledge is partially a product of human creativity and imagination; (4) scientific knowledge is necessarily derived from some degree of subjectivity; (5) scientific knowledge is at least partially empirically-based; (6) scientific knowledge is socially and culturally embedded (p. 38). Unfortunately, these aspects of scientific inquiry and NOS, in particular, have been overlooked in school science (Bybee, 2000).

How do we achieve a more encompassing understanding of scientific inquiry (and NOS) in school science so science learners develop both understandings about and abilities to do scientific inquiry? Teachers would have to create opportunities in the classroom for students not only to engage in inquiry-based investigations, but also to think about what is involved in doing scientific inquiry. To do so, teachers must know first what is meant by scientific inquiry (besides having robust understandings of subject matter and inquiry-oriented teaching strategies) (Bybee, 2000). Unfortunately, many prospective teachers have not learned science in this way and know little if anything about inquiry. How, then, can they realize the vision of reform in their classrooms? It is the responsibility of teacher educators to provide support to teachers in this area. SCIED 410 is a course developed specifically to address certain aspects of this task. In the following section, I will describe the rationale that guided its design.
3 The Program

In recent years, teacher development has been seen as teacher learning (Bell, 1998; Putnam & Borko, 1997, 2000). A major implication of such a perspective is that recommendations for teacher education must be informed by learning theory in the same manner that K-12 education is. At least three central ideas about learning have been identified as central to teacher education: (1) knowledge is situated in a physical and social context (Brown, Collins, & Duiguid, 1989), thus, knowledge about science teaching should be situated in an appropriate context (Putnam & Borko, 1997, 2000); (2) learning is seen as interpretation of experiences and the learner has an active role in that process, thus, teachers should be exposed to new experiences and should have the opportunity to reflect upon them, rethinking previous experiences (Northfield, 1998; Putnam & Borko, 1997); (3) knowledge is socially constructed, thus, teacher educators should invest in building discursive communities of future teachers (Bell, 1998; Putnam & Borko, 1997). Unfortunately, still, the design of pre-service teacher educational programs has not been impacted by such a perspective (Northfield, 1998; Putnam & Borko, 2000). The creation of SCIED 410 represents part of an effort to incorporate key ideas about learning into a teacher education program for prospective science teachers.

One of the main difficulties in teacher learning is that, in spite of the extensive time spent in classrooms as learners, future teachers have rarely experienced the kind of learning that reform is promoting. If teachers need to develop subject matter knowledge and knowledge of subject-specific pedagogy for teaching science, how can science educators better situate and facilitate the development of this complex knowledge? From a situative perspective the answer to this question is: It must be situated in the context of the classroom. However, prospective teachers cannot, like practicing teachers, refer back to past experiences in their own classrooms and try new ideas with their own students. The closest parallel to those experiences would be student teaching. Student teaching has been identified as potentially the most significant experience in pre-service education. Ideally, during student teaching, knowledge accumulated throughout college is applied to classroom contexts (Northfield, 1998). Nevertheless, little is known about how much
future teachers learn during this late stage (Putnam & Borko, 1997), and PTs do not always have the opportunity to work in an appropriate context or even to teach through activities that are consonant with educational reform. More important, it appears that the gap between formal courses and school teaching is not necessarily challenged by the student teaching experience (Northfield, 1998). There is evidence that future teachers hold structured knowledge and beliefs about teaching science that are built through their prior (and extensive) experiences as learners (see for instance, Mellado, 1998). It is unlikely that such a complex knowledge structure will be changed during student teaching – even if that experience was exemplary. In other words, teacher educators should explore additional strategies to situate knowledge about teaching science in the classroom. Although student teaching is a valuable experience for future teachers, it is not sufficient to promote teacher development. Earlier in their education, PTs should be exposed to educational reform views, through experiences that take place in the context of classrooms, helping them to re-think their prior understandings (Northfield, 1998). In sum, it is essential that throughout prospective teachers’ education, educators - including science educators - provide diverse contexts to situate knowledge in the classroom, starting as early as possible.

The impetus to develop a new course for Secondary Science PTs, SCIED 410, derived from a funded project aimed at integrating technology for supporting scientific inquiry into the Secondary Science Education program at our university, during the period of 1999-2000. This experience led to the development of the Learning to Teach with Technology Model (Friedrichsen, Dana, Zembal-Saul, Munford, & Tsur, 2001). Through the process of implementation, the instructional team reflected on how to support teachers’ learning about central ideas in science education. The model derived from the project was conceptualized around elements of the conceptual change model, implying that for learning to occur, new knowledge has to be intelligible, plausible and fruitful. Thus, the phases of the model were conceived to gradually promote these conditions. In Phase I, PTs, as science learners, use technology tools to engage in scientific inquiry (e.g., they use computer simulations to learn about gravity). This phase
supports students in making knowledge intelligible, that is, they come to understand how technology affects science learning. In Phase II, PTs focus explicitly on the technology tool, learning how to use the tool (e.g., set up, trouble shooting, calibration). In Phase III, PTs examine existing technology-enhanced science curricula and/or modify exemplary curricula (e.g., adapt cookbook lessons using probes and turn them into inquiry lessons). In Phase IV, PTs use technology to support students’ scientific inquiry in a supportive small group setting (e.g., middle school students visit the university for a few hours and PTs work in teams teaching with technology). Finally, in Phase V, in a school setting, PTs use technology to support students’ scientific inquiry, using lessons that they design and implement (e.g., during their practicum at school, PTs use technology to teach science in the classroom). Reflection is embedded throughout all phases of the model.

SCIED 410 was designed to provide science learning experiences to PTs earlier in the program to facilitate teacher development. Students majoring in Secondary Science Education are required to take a sequence of three SCIED courses before student teaching. The first course, SCIED 410, is characterized as a science content course. At this stage, which parallels Phase I in the model, PTs engage in scientific inquiry as learners, reflecting mainly about two aspects of science teaching and learning: the nature of science and the nature of science learning. As I will describe later in this chapter, activities were designed to emphasize these themes. As Putnam & Borko (1997) put it, “Because teachers are being asked to make considerable changes in the nature and content of classroom instruction, it is essential that they themselves experience these new visions of education as learners and then reflect on them as learning teachers” (p. 1286).

The other two courses, SCIED 411 and SCIED 412, are Science Teaching and Learning courses (i.e. methods courses). Thus, in these courses the emphasis shifts to developing teaching strategies for supporting science learning, although the two themes mentioned above still receive much attention. At the end of the advanced methods course, PTs spend time in the school setting, first making observations, and then teaching (last 5 weeks). These three courses (SCIED 410, 411, 412) are completed prior to student teaching.
4 Overview of the Course

4.1 Description of the Course

As I mentioned earlier, the course ‘Technology Tools for Supporting Scientific Inquiry’ (SCIED 410) is a science course developed specifically for secondary science education majors. PTs take the course prior to or concurrently with their first science methods course. In the first two semesters that the course was offered, however, it involved a more diverse group of education majors, including prospective elementary teachers, Spanish teachers, and Social Studies teachers.

The Instructors

SCIED 410 was designed and taught for two semesters by a team of 4 instructors: one professor and three doctoral students. The professor worked collaboratively with the graduate students in the design, implementation and revision of the course. As will be further described later, the course was composed of three modules, which focused on different science disciplines (life, earth and physical sciences). Each of the modules had a lead instructor, one of the graduate students. P, who had background in Biology and extensive experience with both teaching high school science and science methods for PTs, was responsible for the Evolution Module. J, who also had extensive experience with high school teaching, was responsible for the module on light, his area of expertise. Finally, I served as the instructor of the Earth Sciences module. My background is in Biology and I had experience teaching high school and working with practicing teachers.

Focus on multiple disciplines

The course was structured around three modules (instructional units), focusing on life science (natural selection), physical science (properties and behavior of light) and earth science (global climate change). Each module was different in terms of the problem that PTs investigated, the activities they engaged in, and the software that was used. Three aspects were part of all the modules: 1) PTs prior understandings on the topic were assessed; 2) PTs were introduced to the technology through activities designed
to support them in becoming familiar with the software to be used; and, 3) PTs had to ‘put their argument in action,’ discussing their ideas in peer review and presenting their final argument to colleagues. Below, I will provide a brief description of each module. In Appendix A, a more detailed description is provided, including the activities for the module, a brief history of the development of the module, and aspects of the nature of science and argumentation that were particular to each module. Moreover, a table summarizing the differences between modules is presented at the end of this chapter (Table 3.1).

The Evolution Module was developed based on technology-infused curricula, the 'Struggle for Survival Unit' (for a detailed description see Carney et al., 1999; Reiser et al., 2001). The problem that was posed to PTs and the data they used to solve the problem derived from an investigation of ground finches conducted by biologists, Rosalyn and Peter Grant, in one of Galapagos Islands. During the wet season of the year 1976, many birds died on Daphne Island. PTs are challenged to explain why so many birds died in that period, and why some were able to survive. An important aspect of the problem is that scientists have reached some consensus in relation to what caused the death of so many birds, while there are still uncertainties about why some birds managed to survive (Grant, 1985; Grant, 1989). In other words, the task did not involve just confirming something that has been extensively corroborated by scientists, and in that sense, we have an authentic scientific problem.

The Light Module originated from an adaptation of the technology-enriched curriculum of KEI (Bell, 1998; Bell & Linn, 2000), but it was transformed to a great extent by the time the present study was conducted. During this semester PTs were presented with the question, “Why do we see what we see?” They conducted a series of experiments to collect evidence to construct an explanation for the problem. Through this question, they were expected to learn about the various properties of light and how images are formed. Thus, instructors coached PTs to respond to the question ‘what happens to light’ when they were constructing their arguments.
Finally, the third (and last) module of the course addressed the problem of Global Climate Change (Global Warming). Like in the Finch Module, the design of the third module was strongly oriented by the curriculum developed at the Northwestern University (Edelson, 2001; Edelson & Gomez). A contemporaneous discussion – which was not part of the original curriculum – was used as context to introduce the topic of Global Climate Change. PTs were asked to take a position in relation to the Bush administration decision that the United States would not adopt Kioto Protocol recommendations (involving, for instance, mandatory reductions in the emissions of CO2), and had to advise their representatives in the matter. To do so, they worked in pairs like in the previous modules, acting as consultants to their representatives. They responded to the following questions, which were adapted from the original context: 1) Are global temperatures increasing? 2) What is causing changes in global temperatures? (Is human activity causing changes in global temperature?) 3) Why is global warming such a big problem? (What would be the consequences of GW? What would be the problem with trying to avoid it?) 4) What would you recommend to the U.S. government about the issue?

We purposefully chose to address different scientific fields for two major reasons. First, we wanted to provide opportunities for PTs to experience at least one of the modules as learners. Given that prospective secondary science teachers major in a science discipline, we expected that they would be more knowledgeable about some modules (those most closely connected to their major) and less so about others. Many teachers do not have robust subject matter knowledge even in their areas of specialization; however, there may be strong resistance to engage as learners in experiences involving content that you are supposed to know. Thus, learning content in other areas was intended to facilitate the process of being a learner of science.

Second, by having multiple disciplines represented in the course, we intended to address one particular aspect of the nature of science that is frequently neglected in school science: the common notion that there is a single ‘scientific method.’ This idea is rarely challenged in classrooms (Brickhouse, Dagher, Shipman, & Letts IV, 2000; Driver,
Leach, Millar, & Scott, 1996; Rudolph & Stewart, 1998), despite the extensive evidence derived from science studies research (Hess, 1997; Knorr-Cetina, 1999). This course represented an effort to support teachers in better representing that aspect of nature of science in schools.

*Doing Science as Argumentation*

In each unit, PTs were confronted with guiding questions (e.g., Why so many finches died in Daphne Island in 1977? What happens to light? Are global temperatures increasing?). It is not a new idea to adopt a question-driven or problem-based approach in science education. One of our major goals for using this approach in the course was to make the scientific concepts and practices part of an authentic context, meaning that learners would be engaged in ways that reflect what scientists do, as well as establish connections with their everyday lives (Brown et al., 1989).

As discussed earlier, knowledge tends to acquire ‘inert’ meanings when addressed in a more traditional way in classrooms. It has been reported that situated experiences help teachers to develop more robust science subject matter knowledge (Putnam & Borko, 1997). Thus, PTs investigated scientific problems in a rich and complex context. They collected data and, working in pairs, they constructed evidence-based arguments. Through argumentation, our students were expected to explore multiple explanations for a problem, provide multiple and relevant pieces of evidence to support their conclusions, make explicit how evidence and conclusions are related to each other, and recognize limitations and strengths in explanations that they build. At the end of the unit, PTs presented their conclusions to their peers. In sum, PTs engaged in all basic activities involved in ‘doing scientific inquiry’ in accordance with reform documents, with an emphasis on “science as argumentation” (National Research Council, 2000). It is worth noting that throughout the aforementioned process, we intended to make subject matter knowledge in science more problematic, that is, shift the focus of science learning from the ‘answer’ to the process (Hiebert et al., 1996).
Constructing Knowledge Collectively

The notion of knowledge as socially constructed that has become increasingly prevalent in science education and teacher education literature (Kelly & Green, 1998; Putnam & Borko, 1997; Roth, 1995) was used to inform the design of course tasks. Although our current conceptions of knowledge, in general, and scientific knowledge, in particular, imply that it cannot be constructed in a social vacuum, school science normally portrays the process of knowledge generation as if it takes place in each individual’s mind in an isolated manner (Driver et al., 1996). The image that emerges from these experiences not only is inaccurate in terms of how knowledge is constructed in “professional science” (Knorr-Cetina, 1999; Latour, 1987), but also fails to promote learning (Putnam & Borko, 1997). In fact, in those settings, scientific knowledge does not cease to be socially constructed, it just is constructed through a “social process” in which learners do not have a voice, and authority defines what counts as scientific knowledge. In SCIED 410, we attempted to create opportunities for science learners to collaborate with each other to construct scientific knowledge, with instructors’ support. In particular, these collective tasks reflected the researcher’s understandings of argumentation in the context of SCIED 410. Our work was guided by the view of argumentation as “dialogic reasoning,” meaning that “Whereas problem solving, in the usual sense of the word, compels one to coordinate internal reasoning structures with some aspect of ... [an external] physical world, ... [argument] compels one individual to coordinate his or her reasoning structures with those of another individual” (Zeidler, 1997, p. 485).

Technology-Rich Environment

In SCIED 410, technology tools were used to assist PTs as they engaged in long-term investigations. These tools, specially designed to support scientific inquiry, provided access to complex databases, powerful analytical tools, tools for organizing data

1 A more detailed description of the software is provided in Appendix B.
and constructing arguments, and access to complex scientific representations through visualization (Reiser, Tabak, & Sandoval, 2001). One fundamental aspect of the “situative perspective” is the distributed nature of cognition (Putnam & Borko, 2000). This notion implies that thinking does not occur in the mind of a single individual, but is distributed among other persons, as well as tools that are part of the physical environment (Putnam & Borko, 1997). In this context, technological tools become pedagogical tools that have the potential to not only enhance cognition, but also transform it quantitatively (Putnam & Borko, 1997, p. 1268).

Most of the technology tools in the course were developed by faculty from Northwestern University. In the Evolution unit, PTs used the software, The Galapagos Finches, a rich scientific environment that provides scaffolding in the process of subject matter knowledge acquisition and the development of domain-specific strategies for constructing scientific explanations in the field of evolutionary biology (Reiser et al., 2001). In the Light Module (Bell & Linn, 2000), probeware and the software, Data Studio (Pasco), were used for data collection; and the software, Progress Portfolio, was used for argument construction. Progress Portfolio is a flexible environment designed to promote and support reflective inquiry, allowing students to record, annotate and organize products of an investigative project (Edelson, 2001). Finally, in the Climate Change unit, PTs used World Watcher, “a scientific visualization and data analysis program designed for learners” (Edelson, 2001, p. 362) and Progress Portfolio to construct their arguments.

**Learning about the Nature of Science**

Following each unit, there were lessons in which PTs reflected on their experiences in the unit and made connections with fundamental concepts associated with the nature of science (e.g., what is theory and its role in science). These lessons are described in more detail in Appendix C. To facilitate discussions, PTs did readings and engaged in activities that explicitly addressed the NOS. Those lessons were designed to support PTs in articulating their conceptions about nature of science and scientific inquiry
in their philosophies. The focus was on the following aspects of NOS: role of theory, science as tentative, science cannot prove but can only disprove, and the influence of values and perspectives on scientific knowledge construction.

There is a consensus in the science education community that science teachers possess inadequate conceptions of the nature of science (Abd-El-Khalick & Lederman, 2000). PTs in particular, “showed themselves to be insecure and contradictory in answering questions on the epistemology of science, and recognized that they had not reflected before about these topics” (Mellado, 1998). Underlying the goal of helping PTs to develop better understandings of NOS is the assumption that such conceptions would influence their classroom practices. However, research has indicated that there is a complex relationship between teachers’ conceptions of the nature of science and teaching practices (Abd-El-Khalick & Lederman, 2000; Lederman, 1992; Mellado, 1998). The major implication of these findings is that initiatives in the context of teacher education can be considered ‘successful’ only if teachers are able “to convey appropriate conceptions of the scientific enterprise to pre-college students” (Abd-El-Khalick & Lederman, 2000). In that sense, initiatives that were oriented by an explicit approach to NOS – in which inquiry-based activities are combined with activities that explicitly discuss aspects of NOS and support reflection – appear to be more effective than those that had addressed the issue implicitly. The explicit approach guided the design of the course.

**Philosophy of Science Teaching and Learning**

The other major task PTs had in SCIED 410 was to develop a web-based philosophy of science teaching and learning, in which they discussed their understandings of the nature of science and scientific inquiry, science learning, and the use of technology in science education. These ideas should be presented with supporting evidence derived from their experiences in the course. Their philosophy was revised after each of the modules and, at the end of the course, PTs were asked to write a reflection on the changes their ideas underwent during the semester.
To see the learner as the one who actively constructs knowledge, instead of a passive receptor of information implies that learners must have opportunities to reflect and construct new meanings based on their experiences in the course. Moreover, it is important for learners to be able to recognize and make sense of the changes in their thinking throughout the course. The philosophy of science teaching and learning was designed to support learners in this process of reflection.

Reflections on Subject Matter Learning

In SCIED 410, PTs also reflected on their own learning. In each module, PTs were asked to comment on articles that discussed common alternative conceptions on the topics addressed in class (e.g., Bishop & Anderson, 1990, research on evolution). As part of the assignment, PTs had to identify their own misconceptions, and discuss possible sources of alternative conceptions. In other words, in the same way we expected PTs to construct new understandings about teaching and learning science, we expected them to develop new understandings about subject matter knowledge in different disciplines. Again, we argue that as active learners PTs need to reflect on their own learning process. In this case, we focused on the recognition of limitations in their own subject matter knowledge, and the tenacity of misconceptions. These aspects were intended to help teachers see themselves as life-long learners with respect to scientific knowledge.

Implications for Practice

Finally, PTs were required to reflect on the implications of their experiences for teaching practice. They had to comment on articles that described experiences associated with teaching the topics being addressed in SCIED 410 to K-12 students, discussing how it would inform their own teaching and establishing connections between the article and class activities. This task, contrary to the others, was explicitly connected to the development of teaching strategies. The reasoning underlying this task was that although PTs engaged in the course to experience a different way of learning science, it was important that they, as future teachers, reflected on how their experiences as learners
would inform strategies for teaching science. Again, reflection is a key aspect in the process of developing new understandings, thus it was an essential part of the task.

5 Defining Argument in the Context of SCIED 410

In this section, I intend to make transparent to the reader key aspects of the instructors’ understandings about argumentation. This is essential information needed to characterize the context in which prospective teachers had experiences with argumentation to learn science, since our understandings informed the design as well as the teaching of the course.

Again, to address this issue I will be using the definition proposed by Costello & Mitchell (1995). These authors suggest that:

… argument can be defined by what it does, as well as by what it, more abstractly, is. (…) So, to answer the question, ‘what is argument?’ entails asking a number of others: what does argument do? who does it? with or to whom? where? and why? Each of these questions links an understanding of argument not to the realm of the abstract and immutable but to the social, interactional world, or more precisely, worlds. (Costello & Mitchell, 1995, p. 1-2)

5.1 Addressing questions within a theoretical perspective

I will first address these questions, and then I will be more specific about what I considered an appropriate argument to be (although it was not always possible to provide opportunities for PTs to construct such an ideal argument). Based on the previous sections the reader may anticipate the answers to these questions, but I believe it is worth making it as explicit as possible. Addressing these questions beforehand is valuable because such elements of our understandings of argumentation were determinant in establishing what the characteristics of an appropriate argument would be. Moreover, they are also considered helpful to understand how and to what extent our notions were
influenced by the work of other authors, making it easier to identify the role that each of these perspectives plays in our understandings.

Two authors had a major influence in shaping our understandings of argument and argumentation: Stephen Toulmin and Dianne Kuhn.

If one contrasts the type of argument we were asking our students to construct with Toulmin’s model (or pattern) of argument, it would not be difficult to identify many parallels between them. However, the reader should exercise caution in relation to these apparent similarities. Throughout this section, I am going to point out parallels between our ideas and Toulmin’s, but I will try to emphasize what elements of this author’s work are not compatible with our perspective. That also is important because the work of Toulmin has influenced many other authors in the science education community who have been interested in argumentation (e.g. Jimenez et al., 2000; Russel, 1983). Although Toulmin’s model offers interesting insights, particularly in identifying major components of an argument, it relies on assumptions that contradict major principles of our work in this course. For instance, the work of Toulmin rests in the notion that “Reasoning is not a way of arriving at ideas but rather a way of testing ideas critically. It is concerned less with how people think than with how they share their ideas and thoughts in situations that raise the question of whether those ideas are worth sharing” (Toulmin et al., 1979, p. 10, my emphasis). This position has crucial implications for the question of “why people engage in argumentation” – that is, with which purposes. For Toulmin, argument is an instrument of persuasion. One would engage in argumentation to convince others of her/his (already developed) ideas. No wonder, he makes a clear distinction between the assertor who proposes the argument, and the questioner who critiques and evaluates such arguments, and, eventually, may change her/his ideas. In other words, from Toulmin’s perspective, as one builds the argument, he/she is not constructing new understandings through that process; but merely verifying and discarding old ones.

Evidently, there is a conflict between the purposes of engaging in argumentation envisioned by Toulmin and those that oriented our course. In this context, prospective
teachers engaged in argumentation to learn science. In other words, they built written arguments and engaged in discussions to construct new understandings of scientific concepts, not just to better communicate or articulate ideas that they already had. I would say that, in this case, reasoning is considered as the very process of developing new ideas.

Dianne Kuhn’s perspective on argumentation is quite different from Toulmin’s, in spite of his influence in her work (Kuhn, 1991, p. 2). Kuhn considers argument as thinking, describing it as a much more dynamic process that underlies the way(s) people make sense of the world around them. In other words, when this author talks about argument, she is referring to not only how one presents/communicates their knowledge about the world and respond to criticism, but to the way they think and construct new understandings. This perspective is much more fruitful when one considers learning as the major purpose of engaging in argumentation because it implies an active role for the science learner who has new experiences and tries to construct new knowledge through argumentation. Although Kuhn doesn’t emphasize aspects of the elements that constitute an argument in as much detail as Toulmin, she focuses on the processes involved in engaging in argumentation, as well as some of the factors involved in such processes. These ideas were quite influential in the development of the instructors’ understandings of argumentation.

So far I have only addressed one of the questions posed at the beginning of this section: “Why do people engage in argumentation?” What about the other aspects mentioned earlier? The notions of who, with whom, to whom, and in which context are all interrelated. Furthermore, they are all related to the question of why people engage in argumentation. The purpose of argumentation, in this case, is directly related, for instance, to the context in which it takes place: an educational institution, or more specifically, a science course for prospective teachers in a College of Education. The

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2 Some authors have argued that the same person can internally engage in both roles (Billig, 1987), however, to reduce the process of thinking to this type of polarized dialogue appears to be quite simplistic.
people who engaged in argumentation in this context should be characterized as not only college students or prospective teachers coming from different areas, but also as *science learners*. In principle, our perspective could be applied to (and derives from) other contexts of schooling with science learners (e.g. K-12 students, college students in a science course). In fact, scholars working in these contexts share some of our ideas about argumentation (Driver et al., 2000; Jimenez et al., 2000; Newton et al. 1999; Osborne 2001).

With whom are these science students engaging in argumentation? Considering our understanding of argumentation as “dialogic reasoning” that compels one individual to coordinate his or her reasoning structures with those of another individual (Zeidler, 1997, p. 485), we tried to emphasize a social perspective with respect to argumentation as much as possible in this course. Since we understood argumentation as a collective process, in the course, we envisioned argumentation as frequently occurring in an interactive social context (i.e., learners were always interacting with each other to build arguments in response to the scientific questions they were confronted with). As discussed earlier in this chapter, science learners engaged in argumentation with their peers. They constructed their written arguments in pairs and they discussed, presented and critiqued their arguments with other colleagues in two occasions in each module. Evidently, the instructors represented other subjects who interacted with learners in the process of argumentation. They provided guidance throughout the course, intervening to maximize interaction between individuals, to help learners consider the various elements of the argument, and to support learners in reflecting on their ideas and better articulating them.

Finally, for whom were learners constructing arguments? This question is understood here as ‘Who was determining what an appropriate argument was? Who set the norms for argumentation?’ The immediate answer to this question would be “the instructors of the course,” however, multiple dimensions of the question can be explored. First, on a more immediate level, learners were submitted to the norms of other learners. In other words, their arguments were submitted to the scrutiny of their peers in many
instances (both as they worked in pairs and as they interacted in bigger groups). Of course, these parameters set by learners were influenced by instructors’ parameters. Nevertheless, learners also brought and developed other parameters based on their own experiences. Second, it is worth noting that instructors’ were informed by ideas of a broader science education community, science community and science studies community. Thus, to some extend their arguments were evaluated in light of certain perspectives present in these various fields of study (and in particular fields within these broad fields). For instance, to build an argument on the death of finches, the learners were expected to comply with parameters set by scientists in the field of evolutionary biology.

5.2 What is conceived as an appropriate argument?

Having provided a description of the fundamental aspects of argumentation in the context of the course, I will now turn to a more detailed description of the characteristics of the arguments that were constructed. As I mentioned before, argumentation in this course was structured around the major tasks of constructing a written argument in pairs, and presenting this argument to peers. Thus, the structure of the written argument was determinant to all the process of argumentation in this context. I will begin this section with a detailed description of the components of the written argument, and then, discuss other aspects of the argument that derived from our understandings of argumentation.

The written argument was composed by a question, claim, evidence supporting this claim, and justification connecting each piece of evidence to the claim.

Question

The starting point of an argument is the question. The question embodies the problem participants want to (or should) address through argumentation. Notably, in SCI ED 410, these problems were usually broken down into sub-questions, which focused on particular aspects. How participants did this was considered an important element of the argument, which could inform how the problem was framed. However, it is important to notice that, in SCI ED 410, both questions and sub-questions were
determined by instructors, and PTs had little choice on how to frame them. An exception would be the Evolution Module in which sub-questions were defined by PTs.

Claims

A claim can be described as a statement that represents the conclusion (or one of the conclusions) learners arrived at in response to the question they were investigating. One of the major concerns when constructing claims has been with the way one articulates his/her ideas. Toulmin and colleagues (1979) were particularly concerned with the ability of the assertor to convey a clear message to her/his audience. Any ambiguities in the claims should be resolved to avoid misinterpretation by the reader (Toulmin et al., 1979). Even when one approaches the issue from a perspective other than Toulmin’s, being able to clearly articulate your own ideas is seen as fundamental. More important, the way one structures a claim will have implications for the evidence they have to provide to support that claim, as well as the nature of justification. To support PTs in making claims that would facilitate the process of argument construction, as well as in reduce the chance of ambiguity, the instructors expected learners to generate claims that were very concise (usually constituted by a single sentence) and very focused (addressing a single point/aspect of their response). This was intended to facilitate the process of evidence choice and justification. An example of a claim would be “Light travels in straight lines.” This claim was generated in response to the question “Why do we see what we see?” It is clear that the claim does not fully respond to the question but, addresses one very specific aspect of the problem. The claim needed to be complemented with other claims and related to them.

It is important, here, to point out an important difference between our notion of claim and Toulmin’s. In his description of the process of argumentation, the first event is the elaboration (and presentation) of a claim. In other words, from his perspective, the claim initiates the process of argumentation. This conception of claim does not reflect what was expected to take place in the course. In this context, PTs were not asked to elaborate a claim at the very beginning of the module. On the contrary, they first engaged
in different kinds of experiences from which they could generate pieces of evidence. Only after these experiences, learners were asked to produce a claim. Taking that into consideration, Toulmin’s concept of claim and ours cannot be understood as analogous. It would be more appropriate to regard Toulmin’s notion of ‘conclusion’ as interchangeable with what we understand as claim. In his words, “The claim that originally formed the unsupported starting point for discussion now becomes – after critical analysis – a more-or-less adequately supported destination, or conclusion” (Toulmin et al., 1979, p.30, emphasis in the original).

Evidence

Evidence can be defined as particular facts, observations, previous conclusions or secondary information (e.g., other people’s reports and observations, representations based on models) that support the claim. In other words, the learner was expected to present what exactly made her/him reach the conclusion stated in her/his claim. There are some parallels between our notion of ‘evidence’ and Toulmin’s ‘grounds.’ However, it is worth noting that, in our case, emphasis was placed on making transparent the path/process to reach a conclusion, not in “making good the previous claim” (Toulmin et al., 1979, p. 33). Kuhn (1991) describes this aspect of the process of argumentation as a response to the question “How do you know?” In the context of this course, one could phrase the question in a similar way but capturing part of a process of knowledge construction that is still taking place (or at least occurred recently): “How are you learning that?” or “How did you learn that?” An aspect of the course that illustrates this is that as PTs built their arguments they were asked to consider pieces of evidence and to explain what they inferred from them (or how instructors sometimes put it, PTs had to “tell the story of evidence,”—“the lessons learned from evidence”).

Two aspects were considered in the evaluation of learners’ evidence provided to support claims: the quantity (or sufficiency) and the quality (or relevance) of evidence (see Sandoval & Reiser, 1997; Toulmin, Rieke, & Janik, 1979). First, we expected learners to support their claims with multiple pieces of evidence. That would indicate
that they understood that reaching a conclusion involves considering and integrating multiple pieces of evidence. However, obviously, to use various pieces of evidence did not necessarily imply the construction of a robust conclusion, the evidence had to be relevant to the claim. The concept of “genuine evidence,” proposed by Kuhn (1991), reflects one basic element of what we meant by ‘relevant’– to be genuine, a piece of evidence is not necessarily conclusive or compelling, it is simply distinguishable from the claim and is something that derives from it (Kuhn, 1993, p. 45).

At a more sophisticated level, we did consider how powerful and compelling the piece of evidence provided by learners was. A certain piece of evidence could be particularly helpful to reach the conclusion, and in this case, it would be more appropriate. In this respect, the criteria necessary to identifying a compelling piece of evidence are highly determined by the context of argumentation. There are few “conditions of relevance” that are valid across various fields and contexts. The pertinence of evidence is directly related to domain-specific criteria, because it is through these lenses that evidence is evaluated (Toulmin et al., 1979; Zeidler, 1997). Thus, in choosing pieces of evidence the learner must rely on their knowledge about the concepts and practices in the specific context of the topic being investigated. For instance, when working with The Galapagos Finches software, to support the claim that “birds with bigger beaks survived the draught” it would be considered more appropriate to use frequency graphs, comparing dead and alive birds across long periods. This set of graphs would reflect key concepts of evolutionary biology, such as change in frequency of a trait in population, differential survival, and change approached through a larger time scale. It is worth noting that the very design of the curricula and technological tools used in the course took this aspect into consideration.

Finally, we also acknowledged the importance of having diverse types of evidence to support conclusions. In some circumstances, this would demonstrate an ability to recognize the diversity of claims and evidence, and how the two components are related. For example, certain claims in The Galapagos Finches software were better supported by field notes (to indicate change in the behavior), whereas others were better
supported by graphs (to show change in patterns in physical characteristics of the finch population). In other instances, the use of different types of evidence can be understood as the learner’s ability to recognize the complexity of a single claim with multiple dimensions that needs to be addressed through the use of different types of evidence. For example, in the Global Climate Change Module, to respond to the question “Are temperatures increasing?” learners could use one piece of evidence to show changes in the distributions of animals that indicated an impact of increase in temperatures and graphs showing a numerical increase in temperature.

**Justification**

Another component of the written arguments in SCIED 410 was what instructors called ‘justification.’ This component parallels the warrant (or guarantee) in Toulmin’s model (Toulmin et al., 1979). Learners were expected to explain how a particular piece of evidence was related to the claim or what reasons led them to choose that piece to support the claim instead of others.

The use of justification “forces” the learner to make explicit the hidden assumptions underlying the choice of certain evidence to support a claim. Thus, the focus of argument building is shifted from “what made me reach that conclusion” to “how did I think to reach that conclusion.”

**Thinking about own explanation: the argument as object of cognition**

So far the main components of learners’ written arguments have been described, however, there is much to be said about the general structure of arguments. In particular, how it can mirror the approach to argumentation that learners have.

Dianne Kuhn has emphasized that “the ability to reflect on one’s own thought is “the foundation of argumentative reason” (1991, p. 238). This ability indicates, first, that learners think about their “theories” as an object of cognition, and, second, that they can establish boundaries between “theories” and evidence. If learners don’t engage in argumentation with that perspective in mind, one is not really doing argumentation in
accordance with instructors’ understandings of argumentation. But, what are strategies or
elements in the structure of the argument that indicate the occurrence of such approach?
Kuhn (1991) identifies three major aspects to be considered.

First, argumentative thinking necessarily implies exploring multiple explanations.
Argumentation is supposed to occur only if different opinions concerning a
problem/subject exist (or potentially exist). An argument that is constructed without
considering alternative explanations is an empty one (Kuhn, 1991; vanEemeren et al.,
1996). This aspect must be examined in learners’ arguments. Often, for instance,
learners construct an argument based on a single explanation, thoroughly supported with
evidence. In these cases, evidence, in fact, is used merely to build an “elaborative
description” of the theory (Kuhn, 1991), and, thus, it would not be appropriate to call this
type of explanation-building an argument. In this case, the learner apparently did not
seriously consider alternative explanations to the one he/she choose to accept. A second
strategy indicating “reflection about one’s own thinking” is the ability to conceive
counter-arguments, that is, the capacity to envision conditions that would falsify the
explanation(s) learners hold as valid. In other words, did the learner consider what
someone who disagreed with him/her could say to critique the accepted explanation.
Finally, a third indication would be learners’ ability to conceive counter-arguments to
other explanations that contradict their own, that is, what one could say as a critique to
alternative explanations (Kuhn, 1991, and Toulmin et al., 1979, called this last aspect
‘rebuttals’, but I will avoid this confrontational language).

Considering all the strategies described above, what would be the characteristics
of an argument that reflects the approach of “argument as an object of cognition?” In
such an argument, for it to be seen as a meaningful one, learners should explore multiple
explanations, they should provide evidence both to support and to challenge explanations,
and they should identify limitations and ambiguities in the various explanations.
6 Classroom Dynamics

After reading about the major characteristics and tasks of the course, as well as about the theoretical framework that oriented its design, the reader may still have questions about what was going on in the classroom. It is not my purpose to give a detailed description of what happened. To construct such a description in an appropriate manner, I would have to analyze videotapes from the classes, paying particular attention to interactions between instructors and PTs, as well as among PTs. I hope that in the future we can learn more about that. Nevertheless, a few words on the ‘routine’ (or routines) of that course, may be useful for the reader to have a general idea of the classroom dynamics.

In SCIED 410, PTs worked in two environments depending on the activities in which they were engaged. Whole class discussions, group work and hands-on activities occurred in a classroom with big tables that were arranged in a way to facilitate group interaction. To construct their arguments, PTs worked in a computer lab, each pair having its own machine. In both environments, we had video cameras to record interactions as a whole class or in the specific pairs. Classes began in either environment, but when PTs arrived, activities for the day were already planned and PTs would be informed about what they were expected to accomplish for that day.

7 Final Remarks: Making sense of Context

Considering that the major purpose of the present study was to better understand participants’ experiences as they learn science through argumentation, one cannot ignore or take for granted the context in which learning took place, in particular, the more immediate context of the classroom. To have a good picture of such a context becomes an issue as we acknowledge the great influence (or power) that instructors and tasks have in shaping the kinds of experiences learners have at school. In other words, how participants perceive their experiences in SCIED 410 is directly connected to what 410
intended to teach (and actually taught), how, where and when it was taught, and to whom, with whom, by whom it was taught. Thus, one cannot make sense of these experiences without knowledge about what the context of the course was. This was the major reason for making this chapter part of this study. However, such a description, though relatively detailed, should not be considered an exhaustive discussion of the ‘context’ of SCIED 410. Why? I would like to emphasize one particular reason for me to argue that my description is limited. I will focus on what my understanding of ‘context’ is instead of focusing on the limitations of information that were previously pointed in the Classroom Dynamics section.

In this chapter, I discussed instructional activities, instructors’ rationales for designing and organizing these activities, and the physical environment of the course (including technology tools), that is, I addressed aspects that were defined and were determined by someone (or something) other than the learner. To assume that these aspects that “reside outside of the learner” fully represent the context would be misleading. ‘Context’ in learning experiences involves both the “external environment” and the “internal” or “personal” processes, dynamically united (Baptiste, Lalley, Milacci, & Mushi, 2002). As these authors put it, the external environment (the description of the course in this chapter represents such environment) would represent “the materials, mechanisms and opportunities learners use to make sense of and manipulate their learning content [i.e., what they learn]” (Baptiste et al., 2002, p. 9, emphasis in the original). In fact, through my interpretations of participants’ experiences, I learned that the ‘context’ that was just described, could assume multiple natures (that is, could become multiple contexts) in light of the meaning different people attribute to the “external environment” of activities, technology tools, instructors, and so on.

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3 Specific behaviors of instructors as teaching also would be extremely influential to participants’ experiences, since teachers’ practices do not always reflect their ideas. However, to focus on instructors’ behavior would compromise my ability to pay attention to learners’ perspectives. Thus, I chose to portray mainly the structure and rationale that oriented the course. I believe that will be enough to give some insights into how the learning context (including instructors) influenced participants’ experiences.
This dynamic notion of context is reflected in Dewey's (1997/1938) concept of “situation,” which I recommend that the reader have in mind when using this chapter. In his view, there is a constant “interaction” between external (or, in his words, “objective”) and internal conditions that constitute a “situation.” In the context of an experience these two types of conditions cannot be separated:

An experience is always what it is because of a transaction taking place between an individual and what, at the time, constitutes his (sic!) environment, whether the later consists of persons with whom he (sic!) is talking about some topic or event, the subject talked about being also part of the situation; or toys with which he (sic!) is playing; the book he is reading (…); or the materials of an experiment he (sic!) is performing.” (p. 43-44)

In addition to that crucial aspect of defining the context (both in terms of ‘concrete’ characteristics and on how these characteristics are understood in this study), in this chapter I made explicit the assumptions involved in the design of SCIED 410, making more transparent the lenses through which I initially perceived this experience. In my opinion, this can be very important for the reader to capture the ‘starting point’ of the researcher in the journey that resulted in the present study. Thus, I also encourage the reader to use the chapter for this purpose. Finally, as the researcher, the design of SCIED 410 influenced the nature of the information used in this study as data sources, as will be further discussed in the methods chapter.
Table 3.1: Summary of the characteristics of each Module, considering aspects of: the problem that was posed, argumentation, NOS, technology used, and teaching and learning.

<table>
<thead>
<tr>
<th>Problem-based</th>
<th>Argumentation</th>
<th>NOS</th>
<th>Technology</th>
<th>Teaching and Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Evolution</strong></td>
<td>- Why did so many finches die? Why some were able to survive? - Sub-questions were constructed by PTs in the process of investigation - Problem involved applying knowledge (concepts and strategies) to a specific context.</td>
<td>- Connections between claims and evidence frequently were ‘obvious’. - Controversy took place outside science. It was discussed but not in the context of the specific problem. - All claims in the same narrative.</td>
<td>- Theory role in framing investigation and response to the problem was emphasized. - Historical science: patterns, non-experimental, field-work. - No direct data collection - Use of both quantitative data (measurements of beak, weight, etc) and qualitative data (field notes on birds’ behavior).</td>
<td>- BGuile: The Galapagos Finches. Designed as of the curriculum. - Power-Point: Presentation - In the same “environment” PTs find all components of the investigation (collection and analysis of data, as well as argument construction). - No explicit field for prompting PTs to include justification in their arguments.</td>
</tr>
<tr>
<td><strong>Light</strong></td>
<td>- Why do we see what we see? (What happens to light?) - Sub-question was implicit and is given by instructors. - Problem involved constructing general statements based on specific events and contexts.</td>
<td>- Controversy is not explored explicitly. - Limited evidence: only evidence that is supposed to be used is provided. - Claims needed to be concise. - Justification was clearly included in the argument.</td>
<td>- Role of theory was not explicitly discussed although there was a unifying theory underlying it. - Experimental: verification through experiments. - Direct collection of data through experiments that were designed by the instructor.</td>
<td>- Use of multiple tools: Probeware for data collection and Progress Portfolio for argument construction - Power-Point: Presentation - Data collection and argument construction occur in separate environments.</td>
</tr>
<tr>
<td><strong>Global Climate Change</strong></td>
<td>- Is global warming occurring? - Sub-questions were developed as a whole class at the beginning of module - Problem involved constructing general statements based on specific events and contexts.</td>
<td>- Highly controversial: PTs were confronted with the two different positions at the very beginning. - Claims needed to be concise. - Justification is clearly included in the argument. - Need to relate question and claim.</td>
<td>- No unifying theory that framed explanations. - Use of secondary data sources (such as articles, web pages. - Science as all human knowledge as influenced by values and perspectives.</td>
<td>- World Watcher: comparisons of visualizations as source of secondary evidence. - Progress Portfolio: argument construction. - Power-Point: Presentation - Using two electronic environments that are easily integrated.</td>
</tr>
</tbody>
</table>
Chapter 4  
Methods of Inquiry

1 Introduction

A naturalistic design utilizing qualitative research methods (Lincoln & Gubba, 1985) was employed in the present study. Many traditions have emerged in the field of qualitative research in which “the researcher identifies, studies, and employs one or more traditions of inquiry” that are suitable to investigate the problem at hand (Creswell, 1998, p. 21). Denzin and Lincoln (2000) describe the qualitative researcher as a *bricoleur*:

The qualitative researcher as *bricoleur* or maker of quilts uses the aesthetic and material tools in his craft, deploying whatever strategies, methods, or empirical materials are at hand” (Becker, 1998, p. 2). If new tools or techniques have to be invented, or pieced together, then the researcher will do this. The choice of research practices depends upon the questions that are asked, and the questions depend on their context (Nelson et al., 1992, p. 2), what is available in the context, and what the researcher can do in that setting” (Denzin & Lincoln, 2000, p. 4).

In particular, this study was conducted within a theoretical framework that combined elements of case study design, grounded theory, and phenomenology (Creswell, 1998; Glaser & Strauss, 1967; Merriam, 1998; Moustakas, 1994; Stake, 1995). These traditions were combined with the purpose of exploring how prospective teachers engaged in the process of argumentation in science. The study involved four prospective teachers, and the data sources consisted of interviews with the participants and their electronic journals.

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1 Different authors had identified different traditions (see, for instance, Creswell, 1998; Merriam, 1998; Moustakas, 1994). Here, I believe it is particularly important to emphasize the perspective of Creswell.
2 Rationale for Qualitative Research Design

Despite the change in the notions of qualitative research through time, Denzin and Lincoln (2000) propose a useful generic definition:

Qualitative research is a situated activity that locates the observer in the world. It consists of a set of interpretive, material practices that make the world visible. These practices transform the world. They turn the world into a series of representations, including field notes, interviews, conversations, photographs, recordings, and memos to the self. At this level, qualitative research involves an interpretive, naturalistic approach to the world. This means that qualitative researchers study things in their natural settings, attempting to make sense of, or to interpret, phenomena in terms of the meanings people bring to them. (p. 3)

Based on such a definition, a qualitative research design was considered appropriate for the present study for various reasons. First, it would focus on the participants’ meanings, that is, on the perspectives and meanings of prospective teachers engaged in argumentation as science students (see also Creswell, 1998). Second, “researchers are interested in insight, discovery, and interpretation rather than on hypothesis testing” (Merriam, 1998, p. 29; see also Lincoln & Gubba, 1985). In the present study, I was not interested in testing hypotheses but in constructing knowledge about argumentation in science learning that was grounded in empirical data (Glaser & Strauss, 1967). Moreover, the goal of this study was not only to describe prospective teachers’ understandings of argumentation in science learning but also to explore factors that can account for such understandings. Third, the study took place in a natural setting, a college level course for prospective teachers majoring in different areas of education (Creswell, 1998). Fourth, the sources of data included a “series of representations”, such as interviews and journals. Finally, the researcher (myself) was a key instrument of data collection and analysis (Creswell, 1998; Merriam, 1998).

(1998), who used discipline orientation as one fundamental aspect to define traditions. This aspect was used as a guideline in the present study.
However, it is worth noting that I do not concur with the notion that qualitative and quantitative are completely distinct and incompatible. As Dey (1993) indicated, quantitative and qualitative dimensions of our ‘reality’ are intertwined and dependent on each other. Thus, adopting a qualitative design does not necessarily imply in the sole use of ‘pure’ qualitative data.

2.1 Case Study

Although ‘case study’ had been frequently described as a tradition (e.g., Creswell, 1998), the researcher shares the position of (Stake, 1998, 2000) that a

Case study is not a methodological choice, but a choice of object to be studied. We choose to study the case. We could study it in many ways (...). As a form of research, a case study is defined by interest in individual cases, not by the methods of inquiry used. (1998, p. 86)

In other words, case studies are better characterized by delimiting the object of study, that is, the case (Merriam, 1998, p. 27).

The present study is an instrumental case study in which the case was prospective teachers’ perceptions of their experiences in argument construction as students in SCIEd 410 (Merriam, 1998; Stake, 1998, 2000). It is worth noting here that the case is not the course but the individual students’ experiences in the context of that course.

The purpose of the study was not solely to *describe* the process of argumentation in science learning but also to gain insight into what factors could be influential to the nature of that process. Thus, this was an interpretive case study (Merriam, 1998).

Interpretive case studies involve thick description of the case (or cases). The descriptive data, however, are used to develop conceptual categories or to illustrate, support, or challenge theoretical assumption held prior to the data gathering. If there is a lack of theory, or if existing theory does not adequately explain the phenomenon, hypotheses cannot be developed to structure a research investigation. A case study researcher gathers as much information about the problem as possible with the intent of analyzing, interpreting, or theorizing about the phenomenon (Merriam, 1998, p. 38).
From the previous discussion, one can infer that the present study contained all the qualities of a qualitative case study as described by Merriam (1998): it was particularistic, descriptive, and heuristic. It was particularistic in the sense that it focused on specific instances (individual prospective teachers) to illuminate a general problem (argumentation in science learning) (p. 30). It was descriptive in the sense that the researcher developed a thick description of each case (including quotes, interviews, and various documents), illustrating complexities, and showing various influences on participants’ perceptions and behaviors (Merriam, 1998, p. 30-31). Moreover, the researcher made an effort to “present information in a wide variety of ways and from the viewpoints of different groups” and “[made] as transparent as possible how different opinions [influenced] the results” (Merriam, 1998, p. 31).

2.2 Phenomenology

The present study was intended to shed light on prospective teachers’ understandings about argumentation in science and science education. Some elements of phenomenological approach are crucial in such an investigation.

Phenomenological inquiry focuses on the meaning that people attribute to experience to understand a phenomenon or phenomena. The phenomenon could be love, anxiety, or, as in this study, argumentation in science. Life-world (Lebenswelt), the world of everyday experience, is an important concept in phenomenology.

This world of everyday experience is not immediately accessible in the “natural attitude.” We take for granted so much of what is commonplace that we often fail to notice it. To really see what surrounds us requires phenomenological study. This task is central to phenomenological tradition. (Cohen & Omery, 1994, p. 139)

Van Manen (1990) illustrates this process involved in phenomenology and its relation to lived-experience through the example of a teacher who wants to understand her/his teaching. When one is actually engaged in teaching, he/she is not consciously reflecting about her/his experiences, otherwise he/she will not be able to live them. At the beginning of a lesson, when the teacher usually is not immersed in his/her teaching,
he/she has an awkward feeling of consciousness of his/her acts, which distances him/her from talking naturally and interacting naturally with students. Later, as the class progresses, he/she stops paying so much attention to his/her own acts and start to live teaching. It is only after the class is over, that, by looking back to the experience of teaching, the teacher can construct understandings about the experience. In sum, it is only by experiencing something and, then, revisiting these experiences with a critical perspective that one can construct understandings about the world.

The issue of lived-experience as the original source of knowledge has been emphasized by various authors, even outside phenomenology (Boisvert, 1998; Dahlin, 2001; Dewey, 1958; Smith, 1999). Knowledge outside the world of lived-experience is limited knowledge, in the sense that it is destitute of meanings, feelings, or purposes in which the experience was embedded (Boisvert, 1998; Dahlin, 2001; Dewey, 1958). As phenomenologists have put it, “We should refer questions of knowledge back to the life-world where knowledge speaks through our lived experiences” (Van Manen, 1990, p. 46).

Although one could argue that any kind of qualitative research focuses on participants’ meanings (Creswell, 1998), phenomenology can be easily distinguished from other traditions by the sole use of the participants’ conscious perceptions of their experiences as source of data (Moustakas, 1994). This notion is at the core of the object of interest of phenomenology:

From a phenomenological point of view, we are less interested in the factual status of particular instances: whether something actually happened, how often it tends to happen, or how the occurrence of an experience is related to the prevalence of other conditions or events. For example, phenomenology does not ask, “How do these children learn this particular material?” but it asks, “What is the nature or essence of the experience of learning (so that I can now better understand what this particular learning experience is like for these children)” (Van Manen, 1990, p. 10, my emphasis).

Moustakas (1994), for instance, defines transcendental phenomenology as “a scientific study of the appearance of things, of phenomena just as we see them and as
they appear to us in consciousness” (p. 49). One fundamental idea in Husserl’s philosophy is that “the only thing we know for certain is that which appears before us in consciousness, and that very fact is a guarantee of its objectivity” (Moustakas, 1994, p. 45). Descartes’ transcendental ideas had a great deal of influence on Husserl in this respect. For phenomenologists (both transcendental and interpretive), reality does not exist apart from the subject that experiences reality, and “only what we know from internal perception can be counted on as basis for scientific knowledge” (Moustakas, p. 45). From this assumption is derived Husserl’s respect for wonders (imagination, memory, or real cases) through which the being brings about its awareness of “its own being and of other beings” (Cohen & Omery, 1994, p. 138; see also Sokolowski, 2000).

The present study relied, in part, on the same assumptions. It is was aligned with the notion that reality does not exist apart from subjects and that one learns about phenomena through the people who experienced such phenomena. It is through rich description of their experiences and wonders that the researcher is able to construct a description of such phenomena. Moreover, the diversity of perspectives related to the same phenomenon enriches the understanding of such phenomenon. However, in the present study, people’s conscious accounts of the phenomenon were not the only source of data from which to understand the meanings of such phenomena. In the present study, I relied on other sources, such as the “products” of their experience (e.g. arguments that prospective teachers built during the experience), and analyzed such products using a very specific framework (established a priori). Moreover, I did not share the assumption that only those who experienced a phenomenon can convey something ‘real’ about such phenomenon. From that assumption, I derived my decision to use other sources of data and ‘external’ lenses to analyze such data. In sum, in this study, I explored other aspects of the phenomenon.

Phenomenological philosophers’ particular interests, evidently, are connected to other aspects of their philosophy and what they intend to illuminate. For Husserl, it is from people’s wonders that the researcher learns about the essences of phenomena, that is, a priori structures of the being that exist independently of time and place (Cohen &
Heidegger, on the other hand, valued the context in which experience takes place. Since, for him, Being and meaning could not be separated; phenomenology would result in understanding about the structures of the phenomenon, aspects that were particular to the context in which the experience takes place and to those who experience the phenomenon (Cohen & Omery, 1994; Ray, 1994). The present study is oriented by Heidegger’s notion of the importance of the temporal-historical context and the denial of the existence of a priori essences of a phenomenon that are independent from time and place.

Another important difference between the two schools is related to the place of description in phenomenological inquiry. For transcendental phenomenologists, description is the essence of phenomenology:

Phenomenology is committed to descriptions of experiences, not explanations or analyses. Descriptions retain, as close as possible the original texture of things, their phenomenal qualities and material properties. Descriptions keep a phenomenon alive, illuminate its presence, accentuate its underlying meanings, enable the phenomenon to linger, retain its spirit, as near to its actual nature as possible (Moustakas, 1994, p.58).

For Husserl the description of truth could be accomplished only if the researcher eliminated her/his prejudgments. Husserl developed the concept of epoche to describe such a notion. Epoche involves suspension of beliefs and suppositions to be able to look at reality naively and to perceive experience in all its richness (Cohen & Omery, 1994; Moustakas, 1994). On the other hand, “Heidegger voiced criticisms of the way Husserl had constituted phenomenology, especially by emphasizing description, rather than understanding (verstehen), as its basis” (Cohen & Omery, 1994, p. 141).

Heidegger’s perspective oriented the present study by this aspect. The intent of the study is not to provide pure description of a phenomenon but to understand it. In this process of understanding, as this philosopher put it, researchers learn through interpretation the meaning of their own Being, and are part of the context in which the phenomenon is illuminated. Even transcendental phenomenologists have acknowledged the limitations of Husserl’s assumption that researchers could completely free themselves
of prejudgments (Moustakas, 1994). Thus, to some extent they recognized that pure
description is an unattainable goal. However, as a researcher, it was important to
appreciate the value of identifying my own perspectives and biases beforehand
(Moustakas, 1994).

2.3 Grounded Theory

Lincoln and Gubba (1985) note that the researcher can use different elements
from different theoretical frameworks, but it is important that he/she identifies the most
influential framework to the design of his/her study. The present study has essential
elements deriving from the grounded theory approach. I chose this tradition mainly
because of its potential to “foster the identification of connections between events”
(Ccharmaz, 2000, p. 522).

Charmaz (2000) defines grounded theory methods as “systematic inductive
guidelines for collecting and analyzing data to build middle-range theoretical frameworks
that explain the collected data” (p. 509). This approach was first present in the late 1960s
by Barney G. Glaser and Anselm L. Strauss who later elaborated on it. The present study
was informed by strategies that these authors developed. However, it also was
illuminated by the recognition of the limitations of these scholars’ work and a
constructivist alternative to their approach (Charmaz, 2000). In this section, I address
some of the essential aspects of the tradition as presented by its founders, and then
discuss how a constructivist paradigm can orient another perspective of grounded theory.

Glaser and Strauss’s ideas, first presented in The Discovery of Grounded Theory
(1967), were the result of their concern with an increasing gap between empirical data
and theory in sociology. For these authors, studies in sociology had involved, basically,
the verification of logic-deductive theories, or pure description with little connection to
theory. They felt an urgent need, however, to conduct studies that focused on generating
theory from data (Glaser & Strauss, 1967). In the beginning of their book, they noted:

Most writing on sociological method has been concerned with how accurate facts can be
obtained and how theory can thereby be more rigorously tested. In this book we address
ourselves to the equally important enterprise of how the discovery of theory from data – systematically obtained and analyzed in social research – can be furthered. We believe that the discovery of theory from data – which we call grounded theory – is a major task confronting sociology today, for as we shall try to show, such a theory fits empirical situations, and is understandable to sociologists and layman alike. Most important, it works - provides us with relevant predictions, explanations, interpretations and applications. (Glaser & Strauss, 1967, p. 1)

Glaser and Strauss (1967) considered “theory as process; that is, theory as an ever-developing entity, not as a perfect product [that could be applied to any context]” (p. 32, emphasis in the original). In other words, what one is doing is in the process of creating a theory is not a final and complete account of a phenomenon (see also Charmaz, 1990, 1994). Theories could have a more limited scope (substantive theories) or a broader scope (formal theories), but they all could be described as being composed of “first, conceptual categories and their conceptual properties; and second, hypotheses or generalized relations among the categories and their properties” (p. 35).

The researcher should make sure that these elements of theory are derived from data. In accordance with Glaser and Strauss (1967),

Generating a theory from data means that most hypotheses and concepts not only come from the data, but are systematically worked out in relation to the data during the course of the research. Generating a theory involves a process of research. By contrast, the source of certain ideas, or even “models”, can come from sources other than data. (...) But the generation of theory from such insights must be brought into relation to data, or there is a great danger that theory and the empirical world will mismatch (p. 6, emphasis in the original).

But how does one generate theory from data? To do so, one has to rise descriptive terms to concepts embodying relationships and having explanatory power (Charmaz, 1990). Two processes are involved in this process of theory generation: constant comparisons and constant questions (Charmaz, 1990, 1994). Making constant comparisons involves:
(a) comparing different people (…), (b) comparing data from the same individuals with themselves at different points in time, (c) comparing incident with incident, (d) comparing data with category, and (e) comparing a category with other categories (…). (Charmaz, 2000).

Raising questions involves looking for assumptions, contradictions and tensions, and absences in the data. What do my categories not encompass? What do these codes tell me about participants assumptions about their experience? What does the occurrence of this contradiction tell me about the significance of the experience for my participants? (Charmaz, 1990, 1994).

In the process of development of a theory, data collection, coding and data analysis are not separate phases. On the contrary, Glaser and Strauss see these taking place simultaneously, although the researcher gives emphasis to one of them depending on the stage of the research (Creswell, 1998; Charmaz, 2000; Glaser & Strauss, 1967).

Theoretical sampling is the process of data collection for generating theory whereby the analyst jointly collects, codes and analyzes his data and decides what data to collect next and where to find them, in order to develop his theory as it emerges. This process of data collection is controlled by the emerging theory (…). The initial decisions for theoretical collection of data are based only on general sociological perspective and on a general subject or problem area (…) (p. 45).

This strategy is essential to the notion of theory as process. Initially, the researcher has a very superficial idea of what is important to understand the phenomena under study, a kind of ‘informed guess’. As the researcher designs the study, he/she selects the groups and aspects based on that ‘guess.’ However, as he/she begins to collect data, the researcher needs to refine his/her methods, now, informed by the data that he/she collected and the constructs that emerged from that data. Glaser and Strauss (1967) used the term “saturation” to describe an important aspect of such integration between data collection and data analysis.

*Saturation* means that no additional data are being found whereby the sociologist can develop properties of the category. As he [sic!] sees similar instances over and over again,
the researcher becomes empirically confident that a category is saturated. He [sic!] goes out of his way to look for groups that stretch diversity of data as far as possible, just to make certain that saturation is based on the widest possible range of data in the category. (p. 61, emphasis in the original)

It is important to note that some aspects of the present study were not completely consistent with some essential elements of grounded theory. First, the collection of data, analysis, and theory development did not occur simultaneously throughout the study, except for the follow-up interview. In accordance with Glaser and Strauss (1967),

When generating theory through joint theoretical collection, coding, and analysis of data, the temporal aspects of the research are different from those characteristics of research where separate periods of work are designated for each aspect of the research. In the latter case, only brief or minor efforts, if any, are directed toward coding and analysis while data are collected. Research aimed at discovering theory, however, requires that all three procedures go on simultaneously to the fullest extent possible; for this, as we have said, is the underlying operation when generating theory. (p. 71)

Second, the study has a very limited scope, and it does not have the potential to reach saturation of concepts generated. In Glaser and Strauss’s (1967) words,

Saturation can never be attained by studying one incident in one group. What is gained by studying one group is at most the discovery of some basic categories and a few of their properties. (p. 62)

These two aspects led the researcher to characterize the present study as a case study informed by grounded theory (see also Stern, 1994).

Throughout the process of theory generation, the researcher needs to be sensitive to the theory that emerges from the data, instead of being guided by preconceived ideas or hypotheses. Since “coding starts the chain of theory development” (Charmaz, 2000, p. 515), coding is decisive to theoretical sensitivity. In later works, strategies to code data are described differently as Glaser and Strauss’s perspectives diverged (Charmaz, 2000). (In fact, such divergence is just an outcome of major disagreements.) The strategies of Strauss and Corbin (1990, 1998) have been extensively applied to qualitative research
(Creswell, 1998). Some authors attribute Strauss’s “popularity” to the fact that Glaser’s work is less accessible, whereas Strauss and Corbin’s is more procedural (Charmaz, 2000).

Coding could be described as a two-step (Charmaz, 2000) or three-step process (Strauss & Corbin, 1998). During initial or open coding, the researcher pays close attention to details in the data, in a way that makes transparent the ways she/he is imposing her/his own views in the data. He/she asks questions about the data, thinks about the meanings he/she makes from the data, and creates codes. The result of that initial phase of coding is the development of some categories and their properties.

The type of concept that should be generated has two joint, essential features. First, the concepts should be analytic – sufficiently generalized to designate characteristics of concrete entities, not the entities themselves. They should also be sensitizing – yield a “meaningful” picture, abetted by apt illustrations that enable one to grasp the reference in terms of one’s own experience. To make concepts both analytic and sensitizing helps the reader to see and hear vividly the people in the area under study, especially if it is a substantive area. (Glaser & Strauss, 1967, pp. 38-37)

Through the axial coding that follows open coding, the researcher establishes connections between categories and subcategories. The initial theoretical scheme that is derived from the axial coding can be presented in a “conditional matrix” that represents the relationships between categories (Strauss & Corbin, 1998). In the following phase of coding, the researcher shifts the focus from data to the categories generated through initial coding. He/she looks at data, now identifying initial codes that reappear frequently to sort large amounts of data. Through that process, the researcher refines his/her categories and is able to explain most of the data (Charmaz, 2000). In the present study, I adopted these strategies for analyzing data, as I further describe in the Data Collection and Analysis section, using examples.

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2 For Charmaz (2000), this is part of the first phase of coding that results in an initial framework for one’s theory.
Many authors have followed a positivist-objectivist perspective when conducting grounded theory studies. In fact, both Glaser’s and Strauss’s approaches reflected their positivist orientation, as if data could offer the researcher slices of the absolute external truth, and he/she could be completely isolated from the ‘discovered’ grounded theory (Charmaz, 2000). However, some authors have challenged the notion that grounded theory is necessarily a positivist theoretical framework (Charmaz, 1994). Charmaz (2000) argues that

… diverse researchers can use grounded theory methods to develop constructivist studies derived from interpretive approaches. Grounded theorists need not subscribe to positivist or objectivist assumptions. Rather, they may still study empirical worlds without presupposing narrow objectivist methods and without assuming the truth of their subsequent analyses. (p. 511)

The present study was oriented by a constructivist paradigm; thus, as the researcher, I adopted strategies to approach data in a way that was coherent with this paradigm. I needed to be aware that I was trying to understand the participants’ meanings, and that from my study multiple realities would emerge (including my own), not the truth (Charmaz, 2000). In particular, different ways of constructing codes and categories can reflect the constructivist perspective. When coding, for instance, the researcher should look not only for “acts and facts” but also for “beliefs and ideologies” (Charmaz, 2000, p. 525). Charmaz (2000) also encourages researchers to make “categories consistent with studied life [to] help to keep that life in the foreground. Active codes and subsequent categories preserve images of experience” (p. 526). She notes that “coding and categorizing processes sharpen the researcher’s ability to ask questions about the data. Different questions can flow from objectivist and constructivist starting points” (p. 526). Axial coding as described by Strauss and Corbin (1998), for example, involves the use scientific terms that would be external to the reality of the one that experiences the phenomena (Charmaz, 2000).
3 The History and the Role of the Researcher

One could call my first formal experience in science education an accident. I was just a biology undergraduate student willing to earn some money before graduation. Education was one of the best options. In Brazil, public schools pay teachers such a low salary that usually students at a good university, like the University of São Paulo, have opportunities to teach part-time. I really liked teaching high school biology, but still I did not intend to become a secondary teacher. I had different plans for my career. I wanted to be a science researcher and a professor at the university. For me, science was the most valuable intellectual endeavor, and I wanted to take part in that.

What fascinated me at that time about science? It is hard to determine. I just remember that I was glad that I did not pursue a major in humanities, despite my interest in that area. My education in science enabled me to consider things more ‘objectively’, and I was confident I would be able to produce something. Scientists use their minds to create things that can improve people’s lives; they are not only generating knowledge, but knowledge that produces concrete things. More important, it seemed to me that scientists have some ‘grounded’ criteria to guide their inquiry; they were not discussing ideas/opinions; they had some facts and real stuff to support their ideas. Those attributes of science would be significant not only in terms of personal, individual accomplishments. In a developing country such as Brazil, it would be essential to have scientists that could take us to the same level of knowledge and technological development as that of developed countries. My country would be able to attain more independence, and many of the social problems could be solved.

It does not mean that I considered science as completely objective. In fact, my interest in human evolution led me to take a few courses in the social sciences, meet historians and archaeologists, and do readings in the area. I was looking more for an equilibrium, where science would contribute in terms of making social sciences ‘more reliable’, while the latter would make the first more value-oriented and ‘politically engaged.’ In sum, at that moment, I recognized in science the possibility of combining
elements of knowledge production that I considered essential. Thus, I definitively decided to become a scientist myself.

It was only later in my life that the accident of having taught at the public school turned out to be a more meaningful experience. After my graduation from my master’s program in evolutionary biology, the idea of getting involved with education started to fascinate me. Through education, other people could have access to the sciences that would provide a better understanding of reality, as well as promote technological/intellectual development for our country. People would be able to understand and change the world in which they live. Again, I was looking for a ‘combination’ of natural sciences with what I considered good aspects of the humanities, notably the notion of the need to take a political position and change the way things are.

This particular interest in education through science intensified as I became increasingly disappointed with science research in the academy. My experience in a research laboratory was telling me that scientists were not those ‘open-minded curious people’ willing to learn more about the world, searching for better explanations. Usually, they were not willing to question foundations of their practice, not even to learn more about the principles that orient and characterize science. In fact, we tended to repeat and follow quite narrow procedures. I felt that this science was not for me as one would have to be too disciplined and objective.

It is worth noting that, at this stage, my disenchantment with science was not related to science itself, but the way science was done and my own ability to adapt to such practices. I had a very partial view of what science was; I still looked at it from the personal/individual perspective, without being able to identify science as a collective institutional endeavor, and make connections between science and the context in which it is practiced. I saw science as a set of procedures, procedures that I took for granted as being science, procedures that per se were not good or bad, but certainly procedures that I could not appropriately engage in. I still believed that the knowledge resulting from that kind of science was the essence of science, and the practices and perspectives involved in its construction were not pertinent to the science learner.
It was in this context that I decided to finally complete the courses that I needed in order to get my certificate to teach biology, and eventually got involved in a project with an underprivileged community. We were supposed to teach science to high and middle school students, as well as give support to science teachers in the school in a city of about 2,000 habitants in rural São Paulo State in my native Brazil. I was involved in the project for one year, and, working as part of a team, I had very fruitful experiences. While I struggled to conceive a different way of teaching science, I evidently faced the very contradictions and limitations of my own knowledge about and view of science. My practice was much more informed by my experience as a scientist than by a reflection on what is science, by experiences in teaching science or by my values. I was still teaching the same science of those who did not share the same concerns (and in the same way) that I had. The same contradictions would be present in the other experiences I would have later, first as a lab assistant in a private high school, and then as an instructor in a professional development program for high and middle school teachers of public schools.

It was only when I came to the U.S. that I started to realize that there could be different ways of knowing, and to think about how knowledge production is shaped by context. In fact, the experience of being in contact with another culture was extremely significant in showing how different ways of knowing can exist. I had just arrived here when I read about Paulo Freire’s experiences in exile in Pedagogia da Pergunta (Learning to Question), particularly the way he conceived the idea of cotidianiedade emprestada (borrowed everyday life). Living abroad meant being in a place where everything that I had taken for granted during my whole life was not the way it used to be.

Nevertheless, as Paulo Freire has said,
… we only learn if we accept what is different in the other, otherwise, there is no dialogue, for instance. The dialogue exists only when we accept that the other is different and can tell us something we don’t know. (p. 36)

One of the greatest challenges for foreign people is to establish such a dialogue. Again, referring to Freire,

If we do not try to (...) critically understand the different, we take the risk of, in the necessary comparison we made between cultural expressions, that from our original context and that ‘borrowed’, applying rigorous value judgments always negative to the culture that is unknown to us. (Freire & Faundez, 1985, p. 26)

In other words, the experience of living abroad per se could not have led me to reflect on different world views and the production of knowledge, particularly of scientific knowledge. On the contrary, it could lead me to refuse to establish a dialogue between different contexts and to question the nature of knowledge. I believe that three aspects were important for me not to take this path: my teaching experiences, being engaged in a research project, and my contact with different theoretical perspectives, through colleagues and courses.

Significant experiences that took me in the direction of bridging the new context with my past experiences included my working with more experienced science educators and my teaching of science to both secondary and elementary prospective teachers. These educators envisioned science teaching as being more than fact transmission. First, they had a different set of goals for science education: the science learner should know not only science concepts but also know about science, and should do science. Second, they were trying to develop new strategies to teach science that would reflect such a

3 Translated by myself from Portuguese: “nós só aprendemos se aceitarmos que o diferente está no outro do contrário não há diálogo, por exemplo. O diálogo só existe quando aceitamos que o outro é diferente e pode nos dizer algo que não conhecemos.”

4 Translated by myself from Portuguese: “Se não tentarmos, (...), uma compreensão crítica do diferente, corremos o risco de, na necessária comparação que fazemos entre as expressões culturais, as de nosso contexto e as do de empréstimo, aplicar rígidos juízos de valor sempre negativos à cultura que nos é estranha.”
vision of science teaching and learning. Moreover, since our students were prospective teachers, it was not enough that they experienced science learning; in addition, they were expected to reflect on that experience, and use such experiences to illuminate their planning and teaching of science. (Of course, our students were presented the same theoretical framework that guided our own teaching.) Initially acting as only an observer, and gradually taking the role of instructor, I was able to follow the same path that the prospective teachers were supposed to pursue.

As I became a full instructor, through my contact with other instructors and professors, and with my students, I was able to think about the limitations and strengths of those ideas and initiatives in light of my experience in teaching science. In these courses, my students engaged in similar experiences that were involved in the course in which the present study took place, such as building arguments and using the same software. In fact, I was part of the team that designed and taught the course for the first time (one semester before the present study data collection took place). Thus, I was aware of most of the aspects of the rationale for the design of the course, as well as of the context in which prospective teachers engaged in argumentation. Moreover, I have a general sense of the kinds of perceptions and experiences prospective teachers can have in the context. Finally, the opportunity to teach the course for a second time helped the team to reflect on our own teaching and to try new things.

Another important experience that I had was to participate in a research project with professors and other graduate students. In fact, the present study is part of this project. The research team worked closely in a pilot study involving the curriculum and software that later was used in one of the modules of the course. We were also interested in questions that were related to the present study. During the pilot study, we engaged in the phases of planning the study, collecting data, analyzing data, and drawing conclusions. Through this process, we were able to identify some limitations in the design of the study as well as to think about other research questions that were worth pursuing. Furthermore, I was able to experience the difficulties and challenges of conducting educational research in an authentic manner and with good support. In a
second phase of the project, we worked in the context of the same course in which the present study was conducted (one semester before). For the first time, I had a chance to interview students with research purposes. I really appreciated the exposure to other people’s perspectives.

As I mentioned before, another important aspect for my own development was to learn about different theoretical perspectives. It was here in the United States, that, for the first time, I had access to theory that could help me to make sense of my experiences as a scientific researcher, science educator, and science learner – and to gain new insights from such experience. Particularly important were readings on the history, philosophy and sociology of science that revealed to me new dimensions of science. In parallel, I have been learning about science learning theories, and was gradually able to make connections between the two fields. In courses related to curriculum theory, I developed a better understanding of how ideas about teaching and learning changed through history, and of how school (and consequently, school science) is connected to the broader social and intellectual context. Finally, through courses in qualitative research I had a better grasp of the various aspects that distinguish qualitative research from the research in sciences that I had done before.

Encountering new experiences and theory created new opportunities for me to interpret my past and to explore new questions in the future. And, particularly, to rethink the relationships between science and education, reflecting on how science education could (and should) imply much more than just acquiring scientific knowledge. The present study took place in a course designed with the goal of having the students engage in some of the practices of scientists, and then reflect on such practice. For me, it represented an ambitious attempt to encourage future science teachers to think differently about science teaching and learning, as well as about science itself.

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5 This term is used by Reiser et al. (2001) to describe their vision of science teaching and learning that implies a change in the culture of science classrooms.
4 The Role of the Participants

The participants in the present study were all college students enrolled in a science education course for prospective teachers. They all agreed to participate in the study by being interviewed four times and being video taped throughout the course for the research project that the present study was part of. They also authorized the researchers, including myself, to use electronic artifacts and other materials that they would generate in the course (see informed consent form in Appendix D). In exchange for their participation, students received extra-credit in the course.

The team involved in the research project recognized the interviews, in particular, as an opportunity for prospective teachers to reflect on their experiences in class, as well as on the notions that they had developed about science, science teaching, and learning, and the role of technology in science education. In our view, participating in the research would be beneficial for dealing with immediate challenges in the course, as well as with long-term dilemmas that could emerge later in their careers. Moreover, one of the goals of the present study was to give voice to the participants (Creswell, 1998). The dissertation narrative includes many quotes from the prospective teachers who participated in the research. I also tried to recognize the constructs that the participants brought to the study instead of imposing theories/constructs on them or the context. Again, my approach reflects my search for understanding and my concern with giving the participants an opportunity to express their views (Creswell, 1998).

Initially, I did not contemplate any other role for the participants in the present study than to provide data to be analyzed. They did not contribute to the establishment of the goals of the study nor to the design of the study, and were not expected to participate in the data analysis or the elaboration of conclusions. Unfortunately, it also was not possible to discuss the findings and conclusions of the study with the participants. Hopefully, before publication of the results of this study that will occur. I believe that both the participants and I as the researcher could benefit from that kind of involvement.
In fact, a formal member checking would be very important to make sure that the participants were given a voice in a study.

5 Site and Case Selection

5.1 The Context of the Study

The present study was conducted in the College of Education of a State University located in the Northeast region of United States. More specifically, the present study took place in a science course for prospective teachers called Technology Tools for Supporting Scientific Inquiry (described in detail in Chapter 3).

This course was selected to conduct the present study for various reasons. First, a central element in the course was to build arguments, both in the process of learning science and in reflecting on ideas about science and science learning. Moreover, prospective teachers not only had to engage in argumentation, but they also had to explicitly discuss how their experiences with argumentation informed their ideas about science and science learning. Usually, argumentation occupies a peripheral role in science courses, or, at least, is not explicitly addressed. Second, in the context of this course, I had the opportunity to assess the students’ ideas about other aspects of science and science learning that might be significant for understanding their conceptions about argumentation (e.g., ideas about the nature of science were part of class discussions, in class questionnaires and their web-based philosophy; ideas about science learning were part of discussions in class, written comments on articles, and their web-based philosophy).

Third, the PTs engaged as students and/or science learners in the course. The purpose of the present study was to understand PTs’ experiences as students and/or learners. The pilot study conducted in an advanced methods course that they take later in the program indicated that at this stage PTs are too concerned with the teaching of
science to engage in argumentation as learners or to reflect about their experiences as learners. Fourth, other research was being conducted in the same course as part of a research project involving the use of technology tools to support science teaching and learning. Thus, conducting the present study in the same context was advantageous in terms of being able to use resources available for that project (for instance, video tapes of classes or students interactions).

Finally, as I further discuss in the next section, the fact that the course was constituted by a relatively diverse group of prospective teachers, at least in relation to their majors, was considered an advantage by the researcher. Secondary Science Teaching and Learning Methods classes tend to be more homogeneous in that respect.

5.2 Case Selection

Four prospective teachers, working in two pairs throughout the course, were selected to participate in the present study.

The rationale for selecting the participants in the study was guided by a naturalistic perspective in the sense that the goal of the present study was not generalization (Lincoln & Gubba, 1985). Many authors had considered the study of the particular that is involved in case studies in terms of its typicality, representativeness or potential for generalization (Stake, 2000). However, I agreed with Stake’s (2000) position that “generalization should not be emphasized in all research” (p. 439). In accordance with this author, since case studies involve thick description, the reader should be able to generalize through vicarious experience (Stake, 2000). In sum, the sampling in the present study was not guided by the notion that its findings should necessarily be generalized.

The case selection was oriented by a combination of factors. The most important consideration was to have the most diverse participants, maximizing the range and scope of information obtained (Lincoln & Gubba, 1985; p. 224; see also Glaser & Strauss, 1967). In the context of a collective case study, that notion gains further significance. As (Merriam, 1998) notes,
The more cases included in a study, and the greater the variation across the cases, the more compelling an interpretation is likely to be. By looking at a range of similar and contrasting cases, we can understand a single-case finding, grounding it by specifying how and where and, if possible, why it carries on as it does. (Miles & Huberman, 1994, p. 29, cited in Merriam, 1998, p. 40, emphasis in the original)

I did not meet the participants before conducting the study; however, there were some attributes of interest (Stake, 1998, p. 102) that could be identified at the beginning of the data collection. First, as previously discussed, I expected the participants’ major to influence their experiences as science learners. Their major was probably related to their familiarity with science content, their motivation and interest to learn the subject, and perhaps the level of difficulty they encountered in learning science. The participants’ majors were: Elementary Education and Secondary Science Education, with an emphasis in Chemistry for one of the pairs; and Spanish and Social Studies for the other pair.

Second, some of their notions about the nature of science could be related to the role of argumentation in science and science learning, as well as to their conceptions of science learning (Hogan, 2000). At the beginning of the course, the PTs were required to respond to a questionnaire on the nature of science (see Appendix C). I also used an informal analysis of these responses to select the cases. My intention was not to systematically and extensively explore their understanding of the nature of science. I used the questionnaire only as another source of information to identify major differences between the participants. Although the participants’ ideas had much in common, they varied in areas such as tentativeness of science, notions of what an experiment is and its role in science, and the origins of controversy in science (Abd-El-Khalick & Lederman, 2000). (Table 4.1 presents the characteristics of each participant.)
Table 4.1: Characteristics of the participants in relation to major and responses to the Nature of Science Questionnaire.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Pair</th>
<th>Major</th>
<th>NOS responses</th>
</tr>
</thead>
</table>
| Conrad     | 1    | Secondary Science Education - Chemistry | - Science is “proven experimentally”  
- Science is “testing a hypothesis”  
- “Scientific theories do change.” and “it is nearly impossible to create a flawless theory”  
- Data can be interpreted differently by scientists. Refer explicitly to scientists biases.  
- Models reflect reality |
| Caroline   |      | Elementary and Kindergarten Education | - Focus on science as knowledge not as way of knowing. Scientific theories and facts “can be proven” (“hard evidence to back them up”)  
- Experiment to test information  
- Evidence can be interpreted differently if it is ambiguous or incomplete.  
- Model of atom derives from direct evidence (observation) not inferences |
| Leila      | 2    | Secondary Spanish Education          | - Define science based on both process and knowledge  
- Hypotheses testing  
- Change as progress: “science constantly tests new ideas”, “new theories build on older theories”  
- “Scientists search for information that particularly supports their own opinions.” Thus, both theories can be viewed as correct depending on the point of view.  
- Model of atom derives from indirect evidence |
| Matt       |      | Secondary Social Studies Education   | - Science as discovery of “the truth”  
- New facts change theories  
- Evidence can be interpreted differently if it is ambiguous or incomplete.  
- Model of atom derives from direct evidence (observation) not inferences |
I also selected cases by considering the gender of the prospective teachers, since their different experiences could potentially influence their perspectives on science learning and science (Brickhouse, 1998). I selected two males and two females for the study.

Another factor that informed the selection of cases was the relationship between myself as the researcher and the participants, and the level of engagement of the participants in the research. The four participants selected appeared to be willing to share their experiences with me and to contribute to the research, both in class and during the interviews. For instance, one of the participants spontaneously suggested that he could share materials from other classes that were discussed in one of the interviews. Another participant after being asked to share materials that would illustrate his ideas insisted on explaining further to me why he selected that piece without my request.

Finally, I also took into account the level of engagement in class activities and the participants’ relationship with their partners when I selected the pairs. I was interested in learning about the experiences of prospective teachers who fully participated in the course. Moreover, considering the importance of social interactions in the process of learning (e.g., Kelly & Green, 1998; Minick, Stone, & Forman, 1993), I expected that the participants in my study had mostly positive and constructive interactions with their peers.

6 Data Collection and Analysis

6.1 Data Collection

The major components of data collection consisted of four semi-structured interviews. In Stake’s (1995) words, “The interview is the main road to multiple realities” (p. 64). Thus, since the purpose of this study was to understand better how PTs
experience argumentation in science learning from their perspective, it was fundamental that I listen to the participants. Thus, the interviews were designed with that in mind:

The purpose of interviewing is to find out what is in and on someone else’s mind. The purpose of open-ended interviewing is not to put things in someone’s mind (…) but to access the perspective of the person being interviewed. (Patton, 1990, p. 278)

Moreover,

Qualitative case study seldom proceeds as a survey with the same questions asked of each respondent; rather, each interviewee is expected to have had unique experiences, special stories to tell. The qualitative interviewer should arrive with a short list of issue oriented questions …. (Stake, 1995, p. 65)

That is why I decided to use what Patton (1990) defines as “the general interview guide approach.” This approach

involves outlining a set of issues that are to be explored with each respondent before interviewing begins. The issues in the outline need not be taken in any particular order and the actual wording of questions to elicit responses about those issues is not determined in advance…. The interviewer is required to adapt both the wording and the sequence of questions to specific respondents in the context of the actual interview. (p. 280)

The advantage of this type of interview is twofold. First, the structure of pre-established issues guarantees that some basic uniform information would be obtained from all the participants. Second, the relatively open and flexible structure permits the respondent to discuss topics of importance to them that are not listed explicitly on the guide, which can emerge naturally during the interviews. In other words, there is still space for individual differences and unique experiences to be expressed (Patton, 1990).

Initially, I had planned only three interviews, which would be conducted during the course, each one after one of the course modules. These interviews were centered on the participants’ experiences with argumentation in SCIED 410. (The guidelines for these interviews are presented in Appendix F). However, later in the research process, after initiating the analysis of data, I realized that I would need additional information about the participants, so I decided to conduct a follow-up interview. This interview was
centered on the participants’ life histories, their personal ideas, and past experiences in education (with emphasis on science). (The questions structuring this interview are presented in Appendix G). In the analysis, I worked only with interview transcripts for the three first interviews, and with the original audiotapes for the fourth interview.

Another source of my data consisted of documents that the PTs generated during the course, more specifically the science arguments that each pair constructed to respond to scientific questions posed in each module. To build these arguments, the PTs used two different software programs: The Galapagos Finches Electronic Journal, and Progress Portfolio. Copies for versions of these arguments for each day of class were available in an electronic format. This source of data could give me insights into the PTs’ actions when they constructed arguments, as well as into the ‘quality’ of their argument based on my instructional criteria, and a certain perspective on learning.

These documents along with the interviews had the potential to provide different kinds of information. First, they could complement information about the PTs’ perspectives on their experience with science argumentation. Second, they had the potential to illuminate some aspects of my perspectives as the instructor, which would be essential to characterize the context of the participants’ experiences. Finally, they could provide information on what Glaser and Strauss (1967) called “local concepts.” In accordance with these authors’ views,

The sociologist [or the researcher] may begin the research with a partial framework of “local” concepts designating a few principal or gross features of the structure and process in the situation he will study. (…) Of course, he [sic!] does not know the relevancy of these concepts to his [sic!] problem – this problem must emerge – nor are they likely to become part of the core exploratory categories of his theory. (…) Also he [sic!] discovers that some anticipated “local” concepts may remain unused in the situations relevant to his problem. (p. 45)

In the present study, local concepts could be grouped into three levels. At a more elementary level, I would have prospective teachers’ interpretation of the task of building evidence-based arguments. At the epistemological level, local concepts would be the
prospective teachers’ epistemological beliefs, their notions about science teaching and learning, and their notions about the nature of science. Finally, at the ontological level, I would have experiences that frame the other levels of local concepts, such as prospective teachers’ identities and their personal experiences. Table 4.2 provides a summary of the data sources and types of information it could provide. It is important to emphasize that I used the interviews to address all research questions, whereas I used the participants’ artifacts mainly to address the first research question (How do prospective teachers perceive the experience of engaging in the process of situated argument construction as students in an innovative science course?) from a particular perspective.

Finally, other sources of data provided information on the context of the course. These included materials from the course such as schedules, descriptions of the assignments, rubrics, and readings, as well as sources on my perspectives, such as my rationale underlying the design of the course, and my notes and comments.

Table 4.2: Types of data, source of information and potential information used in the present study.

<table>
<thead>
<tr>
<th>Type of Data</th>
<th>Source</th>
<th>Information</th>
</tr>
</thead>
</table>
| Interview Transcripts | Individual participant’s interview transcripts | – Participants’ perceptions of the experience  
– Local concepts at all levels  
– Participants’ stories |
| Documents | Science argument electronic artifact | – Participants’ actions as constructing arguments  
– Instructor’s perspective on the experience |
6.2 Data Analysis

The data analysis involved two data slices (Glaser & Strauss, 1967): the participants’ arguments and the interviews as a whole. I analyzed the first set of data in a more intuitive way, whereas I analyzed the interviews following a more systematic methodology of grounded theory. I explain the reasoning for my adoption of each approach as I describe it.

The analysis of participants artifacts containing the arguments that they constructed in class was considered a window on the behavior of the learners as they built their arguments. I adopted this approach with the goal of representing my perspectives on the experience as the instructor. In other words, I as the researcher (and the reader) had a grasp of how the experience was perceived through an instructor’s/professor’s lenses, and was able to contrast these perspectives with those of the participants. To analyze the PTs artifacts, I developed a rubric based on the literature that was used to develop the framework of the course (See Appendix H). The rubric was informed mainly by the literature on informal argumentation; in particular, the work of Dianne Kuhn (1991, 1992, 1993), i.e., causal coherence, the nature of the pieces of evidence used to support claims, how evidence is related to claims, and the characteristics of justification, and research in science education in which the same curricula and software were used (Sandoval & Reiser, 1997). Although I used a general rubric for all three modules, it had to be flexible enough to account for differences between modules. For instance, in the first module, the participants had to explain the occurrence of a phenomenon whereas in the other modules, they used evidence to propose generalizations. This changed the structure of the argument they were expected to construct, consequently affecting the use of the rubric.

In the process of analysis, I examined arguments for both pairs for each of the modules in parallel, that is, I analyzed each of the arguments for the module in relation to a major topic (e.g., causal structure) and then proceeded to analyze the following topic. After the analysis for one module was concluded, I repeated the same procedure for the following module.
I analyzed the interviews in accordance with the strategies of grounded theory I discussed earlier in this chapter. However, initially, I adopted more general strategies. At the beginning of the analysis, I read all the interviews to get a broader sense of the nature of the data. Using paper and pencil, I tagged hard copies of the interviews for aspects that, at that stage, appeared to be relevant and interesting. To make explicit some of the major aspects that I was paying attention to and to ensure that across all the interviews these aspects were noted, I created a list of questions that underlined the reading of the interview (see Fig. 4.1). I used such a list in a way that would not restrict myself to those specific questions. New questions and aspects did emerge through the reading of the interviews, despite my initial ‘perspective’ (Dey, 1993).

Keeping in mind the concern of not adopting an “excessively narrow look” at the data, I read the interview transcripts for all the participants for each of the modules following their sequence in the course, instead of reading all the transcripts for each of the participants in a row. Moreover, in each of the modules, the interviews of the participants were sequenced in a different manner so that I did not read the interviews of PTs who worked together one after the other (e.g., for the Evolution Module: Matt, Conrad, Leila, Caroline; for the Light Module: Leila, Caroline, Matt, Conrad). I believed that this constant variation of participants (and probably of perspectives on the experience) would keep me sensitive to variations in the data and new aspects that could potentially emerge. Indeed, this sequencing turned out to be particularly valuable, considering that, during the data collection, two of the participants had influenced to a greater extent my view of the experience. Notes that I took during this process led to a list of some of the major elements that caught my attention in this first pass through the data, resulting in a chart for the whole course and the various participants. A limitation in this first pass, however, was that, at this stage, I also had a great deal of concern about what the commonalities were among the participants. Soon, I realized that the commonalities would emerge only later in the research, and that, at this point, it would be important to pay attention to the diversity in the data (Glaser & Strauss, 1967).
Figure 4.1: Questions that informed first reading of data.

1. What does it tell me about the way this participant understands argumentation?
   a. What does the argument do for you? And how?
   b. How does he/she see evidence?
   c. How does she/he see justification?
   d. How does she/he see claim?

2. What does it tell me about the way this participant sees/characterizes his/her own learning of science?
   a. What kind of learner am I?
   b. How do I learn best?

3. What does it tell me about the way this participant sees/characterizes science?
   a. How do I see a scientist

4. What does it tell me about the way this participant sees/characterizes the process of teaching science?
   a. What is the best way to teach?
   b. What is challenging to teach?

5. What does it tell me about who this participant is?
   a. How do I relate to science as a person?
   b. What are some characteristics of that person that my have influenced his notions of argumentation?
For initial coding, I read the hard copies of the interviews again, still focusing on one module at the time but varying the sequence for the participants’ interviews within each module. After this second reading, I performed a third, but this time I recorded codes in electronic copies of the interview, using the software *Atlas.ti 4.2*. In this process of moving from working with hard copies to working with electronic files, I revised, created, and eliminated codes. At this stage, although I generated a list of codes, these codes were no longer explicitly connected to the questions. Through discussions with the professors who were supporting me, it became clear that it would be important to re-establish these relationships to create an awareness of what aspects I was contemplating, emphasizing, or overlooking. Considering that most of the codes referred to questions related to a description of the actions of the PTs, the professors and myself inferred that too much attention was focused on behavioral aspects. Although I was willing to create “active codes” to provide a more dynamic perception of the phenomena (Charmaz, 2000), unfortunately I was, in fact, creating “action codes,” which virtually did not reflect meanings constructed by the participants. To shift the focus of the analysis, I generated questions addressing other aspects of the experience. With this list in mind (and in my hands), I revised the coding of the Evolution Module in *Atlas.ti*, and proceeded to review the coding of the interviews for the other modules (i.e., moving from paper copies to electronic files in *Atlas.ti*). Moreover, throughout the revision, I was particularly attentive to possible new codes (and new questions) that would reflect the participants’ perspectives and the significance of their experiences that could be inferred from the interviews (Appendix I presents a complete set of questions and some of the codes generated that relate to them). Initially, the codes generated were descriptive. I reexamed the data multiple times in an effort to make codes more conceptual (Charmaz, 1990), that is, for codes to have an analytic power and to be sensitizing (Glazer & Strauss, 1967). This was a very difficult process for me. Two aspects were key to achieve some progress in this direction: making comparisons and asking questions. As I noted earlier, making comparisons is key to grounded theory. In the present study, making comparisons across modules was particularly important in initiating the process of development of conceptual categories, followed by making comparisons across
participants. Notably, the comparisons that the participants made across modules were very helpful to construct meanings and to infer what were assumptions underlying the perceptions of their experiences. Moreover, questions that occurred throughout the process of ‘conceptualization of categories’ were very important. Questions that I frequently asked of myself were: *What is missing from my interpretation?*, *What are the contradictions that have emerged from these comparisons?*, *What are the assumptions underlying this perception?*. In the next section, I further illustrate this process using the example of how categories for the first research question were developed.

### 6.2.1 From Magic to Processes: Describing and Learning from the Construction of Ideas

A student auditor in one of my methods seminars once observed that “it seems like magic” when the theory starts coming. It seemed magical to her because she only observed, rather than getting her hands dirty with the data; the process of discovery remained a mystery. She could not see the interpretative steps involved in the process of analysis.

These words of Stern (1994, p. 217) illustrate my goals, as well my challenges while engaged in this research. I wanted to make transparent the process through which I constructed my categories, both to others and to myself. However, this was not a common practice in my experience. To be a magician was not only a habit but also a temptation: to create something from nothing, to entertain, to fascinate, to make the impossible, to be admired, to be mysterious. Moreover, as I engaged in research, I realized that I had a serious misconception: whenever I was trying to make my process of analysis transparent and systematic, I would try to suppress creativity in this process. However, later in the research I understood that this was not the way it is. Creativity is always a key aspect of research, and this becomes another element to be described as we reveal how theory was (or is being) developed (Stern, 1994).

In this section, I describe part of the process I went through as I constructed a response for the research question: *How do prospective teachers (PTs) perceive the experience of engaging in the process of situated argument construction as students in a*
innovative science course? I believe that describing the process of developing categories is not only an important part of doing research but also helps one to understand the concepts underlying the categories, as well as situating them in a context. These intimate interconnections between concepts and their ‘history’ are reflected in the next chapter, in which sometimes I refer to how categories were generated to better explain their meanings.

One could describe the PTs’ understandings about argumentation in the context of science learning in SCIED 410 in various ways, but what would be an appropriate description considering my perspective and concerns? The most important aspect of such a description would represent an interpretation of the participants’ ideas. Putting it simply, what, in my interpretation, would the PTs enrolled in the course have to say about the experience? Such an account could not simply be a version of the instructors’/researcher’s ideas. In other words, evidently, the way the course was designed influenced the PTs’ experiences, but what else would they have to say? Once my objectives and my perspective were set, it might seem quite straightforward to envision at least what a response to the first research question would not be like. However, it was interesting how, despite my consciousness of these perspectives in the process of constructing theory, I initially followed a path which neglected my participants’ experiences. Was it the instructor inside the researcher trying to find out whether the course worked and whether it was a successful experience in accordance with criteria that were valued beforehand (i.e., ideas that pre-existed the participants)? Was it myself as the researcher who had difficult using theory in a different way? It is hard to determine precisely if the evaluation syndrome or the imposing and non-dialogical habits led to an equivocal path. Probably, it was a combination of both. Anyway, initially I could only see reflections of my own practices and ideas as instructor/graduate student/researcher in the data. This is evident in the initial coding (as well as in some of the questions they answer to). Examples of these initial codes would be:

- backing up claims - significance
- backing up claims with evidence
- justification: need for can vary
- justification: role
- looking for supporting evidence
- making claims compact

A description deriving from such codes would lead to a portrayal of argumentation and argument that would not be very different from my own. This description was centered on the idea that the participants would see argumentation as structure, which had as its central elements in claim, evidence, and justification (e.g., they had to separate ideas into the categories of claim, evidence and justification; claim needed to be concise; argument had to be supported with evidence, argument had to have justification). This loosely defined concept of argumentation as structure would tell me, basically, that, in the context of SCIED 410, the learners had a perception of argument that was determined by my instructional guidelines. Besides that, such a description provided me a sense of what were the elements of this pre-determined structure, which the participants had (or had not) difficulty with. Notably, this concept could at most add to what is available in the literature, but it has little potential to challenge and offer us new insights into the process of argumentation. Moreover, this concept was at such an elementary level of abstraction that it represented merely a “description” of the data, with a limited analytical element. Note that the lack of clear interpretation had serious implications, reinforcing a notion of argumentation that was based mainly on behaviors displayed by argument constructors.

An alternative to this concept only emerged as I made an effort to raise the level of the abstraction of the codes composing the concept (argument as structure) through comparisons of different pieces of data (Glaser & Strauss, 1967). A key example of this process was in my attempt to characterize the sub-category evidence: you can’t say anything without evidence and my re-examining of quotes under other codes, namely “multiple pieces of evidence – significance” and missing evidence – confusion. The first category was defined as “participants talk about how you need to have evidence to construct explanations”, whereas the second was “how they experience the lack of
evidence – when they cannot find/identify a piece of evidence, participants felt confused, one should be able to have all evidence available.” At that point, the category of *you cannot say anything without evidence* was seen as having the higher level of abstraction below *argument as structure*. Figure 4.2 represents the relationship between these categories.

I was trying to learn how participants characterized *evidence*, that is, what the key elements of this *indispensable* component of the argument’s structure would be. For instance, from *missing evidence – confusion*, I inferred that one of the characteristics of evidence was that it should, by nature, always be available for examination; otherwise, argument construction would stop there. Note that, at this point, I directed the process of theory construction to build the same initial structure that informed the design of the course, which was now being informed by learners’ perspectives as well. This structure reflected mostly the outcome or product of argumentation (e.g., discourse composed of claim, evidence, and justification), and not much about the process involved. The participants’ experiences were not contributing to learn more about the process of argument construction, which I still described through the lenses of *ideal products* envisioned by the instructors (and consequently, the instructors’ goals and objectives).

This cycle of reproduction of one’s own ideas was broken only when I played with the initial hierarchical relationship between concepts. The question I posed then, *What if “you cannot say anything without evidence”* (A) *was contrasted with “missing evidence – confusion”* (B)? (see Figure 4.3). Initially, I framed these contrasting question with the notion of what the differences are between having and not having evidence. However, richer concepts emerged as I tried to grasp what differentiates instances under these two categories. Within this context, A would tell me about how one is not *allowed* to say anything if he/she does not support his/her claim with evidence. It would refer to some general and abstract *rules*, which were not necessarily rooted on experience but were taken as very important criteria driving their actions in the process of knowledge construction. B, on the other hand, would tell me how hard it is to construct an explanation without evidence, that is, how important having evidence would be to even
create or articulate an explanation. In sum, underlying A was a notion of having authority to say something, whereas underlying B was the notion of having ability to say something.

In light of these two concepts that were developed, B was renamed when missing evidence gets in your way, reflecting how missing evidence would hinder the students’ abilities to construct arguments (and consequently, how the structure given by instructors was normally used as a guide in the construction of arguments). Moreover, it was possible to associate codes that described actions/behavior with codes (A and B) that would reflect each of these categories. And sub-categories within each of them were developed.

Once some of the categories were defined, it was extremely important to ask the question What is missing? to help identify not only the limitations of the experience per se but also to see when these limitations were perceived by participants and/or were reflected in their experiences. Other instances in which argument construction was related to ability were identified and grouped under the category impediments. As I asked what is missing, I thought about my conversations with one of the participants in which she talked about not having room for creativity when they constructed arguments in the course. I realized that this was an important element of their understanding of the process of argument construction. As I examined the quotes with that in mind, I was able to identify other quotes related to the issue, and, consequently, better able to characterize the category. Thus, I grouped argument construction as impediment and argument construction as guidance under a major category called argument construction as means to understand.
Figure 4.2: Initial relationships between some of the categories that constituted the concept *argument as structure*.

Figure 4.3: As I compared data at different levels, the relationships between categories were altered, and new concepts emerged.
6.2.2 Generating a New Research Question

During the process of data analysis, it is not uncommon for researchers to reformulate research questions or even generate new questions. In grounded theory, for instance, in earlier stages of the research, questions are expected to be more open and ill defined. It is through the process of research that they are refined (Charmaz, 1990). In the present study, my initial research question referred to a process that was supposed to be related to learning; however, I did not plan to gain knowledge of the participants’ perspectives on learning. Interestingly, as I examined the data, their perspectives on learning were interpreted as an important element of their experiences. Therefore, I decided to explore another research question:

What are the participants’ perceptions of learning that emerged in the context of the process of argument construction in SCIED 410?

This new question illuminated issues that I did not expect would be (or could be) addressed and contributed to a richer understanding, on my part, of the participants’ experiences in science education.

6.3 Computers and Qualitative Research

In the present study, I conducted the analysis using the computer software Atlas.ti. The use of computer software for data analysis has a series of advantages, but some limitations have also been pointed out (e.g., Dey, 1990). My decision to use software was driven by its potential to facilitate data retrieval, as well as to permit me to group data in multiple ways (Dey, 1990). Moreover, I could construct a record of the progress of my research through time by keeping versions of the analysis file.

Atlas.ti was my choice because of two major advantages it has over other software. First, at the beginning of the analysis, this software enabled me to code without needing to commit to an organization or hierarchy of codes. Second, the relationships between codes were established through the use of ‘networks’, facilitating their
visualization and making it possible to explore different organizations and different types of relationships.

7 Issues of Trustworthiness

The naturalistic inquirer soon becomes accustomed to hearing charges that naturalistic studies are undisciplined; that he or she is guilty of “sloppy” research, engaging in “merely subjective” observations, responding indiscriminately to the “loudest bangs or brightest lights. (Lincoln & Gubba, 1985, p. 28)

How do we know that the qualitative researcher gets it ‘right’? Are we developing the interpretations we want? (Creswell, 1998; Stake, 1995)

How can an inquirer persuade his or her audiences (including self) that the findings of an inquiry are worth paying attention to, worth taking account of ? (Lincoln & Gubba, 1985, p. 290)?

These questions represent scholars’ concern about quality and credibility in qualitative research. In more conventional approaches to qualitative research, certain authors have addressed methodological issues in an isolated manner, and have usually tried to make parallels with research in the natural sciences, particularly experimental sciences (Creswell, 1998; Lincoln & Gubba, 1985). Conventional researchers are usually concerned with four aspects of their research, i.e., truth value, applicability, consistency, and neutrality. The criteria for evaluating these aspects within the conventional research perspective are, respectively, internal validity, external validity, generalization, reliability, and objectivity (Lincoln & Gubba, 1985). Lincoln and Gubba avoid making a parallel with the ‘hard’ sciences (see also Creswell, 1998). These scholars acknowledge the importance of developing criteria for establishing the quality of a study but do not see conventional criteria as appropriate for qualitative research. They challenge positivist conceptions – and consequently their terminology - and propose a distinct approach to assess quality in qualitative research. The latter perspective has oriented the design of the
present study. The trustworthiness of this study was determined in terms of credibility, transferability, dependability, and confirmability.

The notion of *credibility*, the counterpart of internal validity, is informed by a particular notion of reality. Conventionally, reality has been seen as external to the observer and absolute, whereas the naturalist considers reality from a constructivist point of view. Thus,

In order to demonstrate “truth value,” the naturalist must show that he or she has *represented those multiple constructions adequately*, that is, that the *reconstructions* (...) that have been arrived at via the inquiry *are credible to the constructors of the original multiple realities.* (Lincoln & Gubba, 1985, emphasis in the original)

The criterion of *applicability* addresses the same concerns as the criterion of external validity but, instead of focusing on characteristics of the *population*, the qualitative researcher takes into account how different/similar are the *contexts* in which the research takes place and to which the research findings should be applied. The notion of *dependability*, like the notion of credibility, is related to a different conception of reality. For the conventionalist, *reality* is constant, while for the naturalist it can change. Thus, for the former, the major concern is with the procedures and instruments used in the study: they must be replicable and should yield similar findings. On the other hand, “the naturalist seeks means for taking into account both factors of instability and factors of phenomenal or design induced change” (Lincoln & Gubba, 1985, p. 299). Finally, the criterion of *confirmability* challenges the conventional notion of neutrality, that is, the notion that when confronted with *reality*, “it is possible for an observer to be neither disturbing nor disturbed” (Lincoln & Gubba, 1985). As a consequence, to assess the level of the ‘objectivity’ of a study, people had focused on the researcher. However, Lincoln and Gubba (1985) proposed that the emphasis be on characteristics of the data, not on those of the researcher. The reader should ask whether the data is *confirmable*. The present study was designed to take into consideration the importance of meeting all these trustworthiness criteria.
To increase the probability that credible findings would be produced, I spent considerable time on the context of the study. During the semester in which I conducted the present study, I came to every class during the course with the intent of making observations and helping students when requested. I also frequently read PTs’ assignments. It is worth noting that I did the same during the previous semester. Moreover, I interviewed the participants three times during the semester, in a way that I could learn about changes or new ideas that had emerged during different phases of the course. Finally, a few months later, I interviewed the participants again, reestablishing connections. One could argue that this prolonged engagement was not long enough for me “to be able to survive without challenge while existing in that culture” (Lincoln & Gubba, 1985, p. 302). However, it was long enough for me to detect and take account of personal distortions (Lincoln & Gubba, 1985, p. 302) that were involved in participating in the design of the course and in being the instructor of the course (e.g., the expectation that my students would see my instruction as the most appropriate way to learn science and to build arguments); in being a foreigner[e.g., taking for granted that American and Brazilian students would have a similar education]; in being a novice researcher (e.g., learning to pay attention and to assess participants’ perspectives, instead of focusing on my own preconceived ideas). My prolonged engagement with the students also provided some insight into the participants’ distortions that could emerge during the data analysis, such as ignoring challenges and difficulties that they encountered, and being willing to please the investigator.

Finally, the prolonged engagement was fundamental to building trust with participants. I acknowledge the problems resulting from being an instructor in the course (see Limitations section.). However, despite such drawbacks, I believe that it was important for the participants to know that I, somehow, was also engaged in the process

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6 In the particular case of a study involving a foreign researcher, it is also important to note that the context of higher education in the United States was also in part new to me. In this sense, it was very important to observe and to teach classes before I conducted the study. Through such interaction with American college students for about two years, I was able to better understand the perspectives of my participants.
of their science learning, instead of being someone who had no commitment to them as students. Moreover, through our interactions as student-instructor that are natural in that context (including informal interactions), we were able to start to know each other better. The interviews were also very important for building a relationship between myself as the researcher and the participants. Progressively, the participants appeared to be more open to communicate their ideas to me, and apparently felt comfortable asking questions about the research, the course, and myself. Moreover, my interest in aspects of their lives outside the course appeared to be particularly significant to them as well. They demonstrated enthusiasm in talking about their families, friends, hobbies, and life-histories, as evidenced in my follow-up interview with them. Having that opportunity was important to build trust.

Another strategy that enhanced the credibility of the present study was triangulation of both sources and methods. In this study, multiple sources were used to confirm the same information (Creswell, 1998; Lincoln & Gubba, 1985; Stake, 1995; Glaser & Strauss, 1967). “Multiple copies of one type of source” were used to understand the phenomena (e.g., I interviewed more than one prospective teacher, and electronic journal with participants’ arguments were analyzed for more than one pair) (Lincoln & Gubba, 1985, p. 305). Moreover, I used “different sources of the same information” (e.g., I assessed information about the participants’ abilities to build scientific arguments, following my guidelines through participants responses in the interviews, as well as their written arguments) (Lincoln & Gubba, 1985, p. 305). In the present study, different data collection modes permitted triangulation of the methods (i.e., I interviewed the participants and analyzed the written documents as well).

Member checks are considered the most crucial technique for establishing credibility ….. If the investigator is to be able to purport that his or her reconstructions are recognizable to audience members as adequate representations of their own (and multiple) realities, it is essential that they be given the opportunity to react to them. (Lincoln & Gubba, 1985, p. 314)
Of course, the researcher is not obligated to concur with the participants’ criticisms, but “he or she is bound to hear them and weigh their meaningfulness” (Lincoln & Gubba, 1985, p. 314). In the present study, informal member checking occurred during the interviews as I asked participants to confirm whether their ideas were interpreted accurately. Initially, I planned to have member checks of my results and conclusions; unfortunately, I was unable to meet with the participants in time for member checks at the end of the research.

In the present study, I attempted to meet the criterion of transferability by providing thick description. Through vicarious experience, the reader can identify similarities and differences between the context of the present study, and the context of his/her study (Creswell, 1998; Lincoln & Gubba, 1985; Stake, 1995, 1998). As Lincoln and Gubba (1985) noted, the reader not the researcher is responsible for establishing if (and what) elements of a study can be applied to another context, since he/she is the one that knows this context better. As the researcher, I provided a detailed description of the course in which the study took place, of the participants’ themselves, of PTs’ perceptions about their experiences, as well as, of the artifacts PTs’ produced. I used quotes and images to make sure that the reader has access to part of the original data.

Finally, I established an audit trail to address dependability and confirmability criteria. As described in (Lincoln & Gubba, 1985), the audit trail included:

- **raw data**, such as transcripts of the interviews, electronic copies of the artifacts that participants created (i.e., electronic journals)
- **data reduction and analysis products**, such as field notes of in-class observations and assignments, as well as, theoretical notes that include working hypotheses and hunches (Lincoln & Gubba, 1985, p. 319)
- **data reconstruction and synthesis products**, such as axial, open, and selective coding (stored in an electronic format), and, evidently, the dissertation document.
- **process notes**, such as journal notes in which methodological issues are considered.
- **materials relating to intentions and dispositions**, such as journal notes.
- **instrument development information**, such as the pilot forms of interview protocol.
It is worth noting that triangulation also increases the possibility of meeting the criterion of confirmability. Moreover, other aspects of the design of the study should also enhance dependability. First, I tried to contemplate different perspectives, in an effort to explore “all reasonable areas” (Lincoln & Gubba, 1985, p. 324). Second, I searched for both data that confirm and challenge my propositions. In sum, I share Lather’s (1991) opinion that “the character of social science report changes from that of a closed narrative with a tight argument structure to a more open narrative with holes and questions and an admission of situatedness and partiality” (Creswell, 1998, p. 198). Thus, I expected questions and alternative perspectives to emerge from my narrative.

8 Limitations of the Study

Any study has limitations: researchers make choices, and consequently (consciously or unconsciously) overlook aspects that may be important to understand the phenomena under study. Gubba and Lincoln (1991) noted that case studies, in particular, “can oversimplify or exaggerate a situation, leading the reader to erroneous conclusions about the actual state of affairs. That is, they tend to masquerade as a whole when in fact they are but a part – a slice of life” (p. 377, cited in Merriam, 1998, p. 42). Thus, it is essential that I acknowledge the limitations of the study that I am aware of.

Accordingly, I recognized several limitations in the present study. First, it was important to identify which ‘slice of life’ was chosen as the focus of this study. I wanted to understand prospective teachers’ experiences with argumentation in science. An important component of the context in which such experiences took place (a science education course) was instruction. In other words, the way the course was designed, the tasks involved in the course, and the interactions between myself and the prospective teachers influenced their experiences to a great extent. I have provided a detailed description of that context, particularly with respect to the course design and the tasks involved in the course. Even so, in the present study, much was missed in terms of the instructors’ (including myself) interactions with the participants. In the interviews, the
PTs referred to critical interactions, although other interactions that may have been significant, but were not mentioned by participants, were probably overlooked in the study. To capture this aspect of the context in detail, I would have had to pay close attention to instructors’ discourse in class, as well as to instructors’ interactions with the PTs, relying on observations and videotapes. However, I could not conduct a research of these dimensions within a feasible time.

It is also important for the reader to be aware that the present study did not thoroughly explore the behaviors that PTs adopted to build arguments. I recognized that the actions through which arguments were constructed and evaluated had great potential to inform me about how students learn through argumentation. Moreover, a detailed investigation of their behavior could have exposed aspects of their understanding of argumentation that would not otherwise be accessible to me. In fact, my experiences in a pilot study appeared to confirm such a notion. Again, to learn about such aspects of the process in detail, I would have had to make close observations of peer interactions and analyze the tapes of peer interactions for all the classes. That would have demanded an enormous amount of time and would have compromised other aspects of the research. Instead, the present study focused only on interactions as described by the participants in the interviews. This aspect, as I discussed earlier, was more pertinent considering the focus of the study.

Another limitation that needs to be recognized is that I chose to include in the present study only PTs who appeared to be engaged in the activities of the course, as well as those who had established a good relationship with me. Possibly students who were not engaged in the course had different perceptions about the experience that were not represented in this study. I acknowledge the importance of these individuals’ perspectives to better understand the phenomena under investigation. However, considering that little is known about how PTs engage in argumentation, I chose to focus on the perceptions of participants who appeared to be valuing that experience. I assumed that these participants valued the experience because they were gaining (i.e., learning) more from the course. I expected that they probably would be able to make more
connections between argumentation and science learning if they were already experiencing argumentation in the context of their learning. This was an important aspect of the present study. Furthermore, as the researcher, I was the key instrument of the data collection, and if the communication between myself and the participants was not good, the data collection would be highly compromised. I believe that much less can be learned from a study if the participants are not engaged in the process of research and do not value the study.

Another significant limitation of the present study is that I was one of the instructors in the course in which the present study was conducted. I repeatedly emphasized to the participants that they should try, during the interviews, to consider me as not being their instructor, that what they said would not affect their grades, and that they should try to be as sincere as possible. However, I am aware that my role as the instructor could not be separated from my role as the researcher in this study. I believed that the participants would feel more comfortable sharing their ideas if they had a different kind of relationship with myself as the researcher, in terms of power. Moreover, since they knew that I was involved in the design and teaching of the course, they may have believed that I was expecting them to say positive things about their experiences. Considering that, I encouraged them to talk about difficulties that they had or problems that they identified. I repeatedly expressed how I valued their criticism. Moreover, I interviewed them after the course was completed. Yet, I am aware that this did not eliminate the problem of PTs not feeling completely free to discuss their experiences in the course.

Another important limitation to consider is that, as mentioned before, the students who agreed to participate in the research were rewarded extra credits in the course, further exacerbating the connection between grades in the course and their participation in the research.

Part of the data sources for the present study consisted of assignments for the course that were graded (i.e., PTs’ electronic journals with arguments). PTs enrolled in the course were aware that if they did these assignments, following certain guidelines,
they would get better grades. In other words, I recognized that the participants were not free to, for instance, construct arguments the way they thought was more appropriate; on the contrary, they received much guidance and, in a sense, were quite constrained. However, this limitation is directly related to the purpose of the study, which was to better understand argumentation in the context of school science from the students’ perspective. Education inevitably involves having a project in mind, providing students with guidance, and, consequently, poses many constraints.

Finally, another limitation that deserves the reader’s attention is that in the present study, the PTs engaged in argumentation in a quite complex context. Many factors were changing throughout the course (e.g., science content, major instructor, software). Thus, it was hard to establish relationships between the prospective teachers’ notions about argumentation and specific factors. As one considers this limitation, first, it is important to understand that the study took place in a ‘natural setting’ that could not (and should not) be controlled/manipulated to fit the research. Second, in my opinion, such complexity of the context contributed to the present study in the sense that the participants experienced more diverse conditions in which they engaged in argumentation in science. Finally, the understanding of explanation involved in this study was different from the positivist concept of causality (Lincoln & Gubba, 1985). Thus, my goal was not to establish these specific relationships.
Chapter 5
Assessing Participants’ Learning Through Artifacts

In the following sections and chapters, the reader will be invited to follow a journey with the researcher. In this journey, I struggle to break with some assumptions about doing research that go against my orientation, but which are so ingrained in research practices that they are at times transparent and difficult to confront. This journey did not reach an end, but the initial chapter of the story is told through this study. Because the dissertation results and discussion were organized around this journey, the structure of this study may seem ‘unconventional’. However, I was concerned with being able provide a response to the research questions, as well as with make apparent the process of constructing these responses, making it possible for the readers to construct their own understandings about the study. In other words, I tried not to compromise the quality of the study as I constructed the narrative: this study is not only about a ‘story of my journey’ but also about stories I tell about participants’ journeys and what is learned from them.
1 Introduction

In this chapter, I will describe and discuss the results of an analysis that was oriented by a particular approach to the question of participants’ understandings of argumentation, the processes through which they constructed arguments, and how they learned science through these processes. In Chapter 2, I discussed perspectives on learning and positioned myself in relation to them. In this chapter, my approach will not be coherent with the position I espoused earlier. Here, I address the issue of prospective teachers’ understandings and experiences with argument construction using an approach that is more consistent with the perspective that learning is the ability to reproduce certain structures and concepts (see my comments on behaviorism and cognitive perspectives on learning in Chapter 2). In sum, in the present chapter my goal is to tell a story from a perspective other than my own, and to identify limitations (and maybe strengths) of this perspective in a concrete and situated manner.

I examined the ‘products’ of the experience of building arguments to learn science (i.e., the arguments PTs constructed at different stages in each module), and I tried to assess the ‘quality’ of the arguments that were constructed using the theoretical perspective of the SCIED 410 instructors. Through this analysis, I intended to examine what participants did throughout the course in each of the modules. What were difficult/simple aspects for PTs in constructing arguments? What changes in the way they built arguments occurred through the course and within each module? What actions became routine in argument building? Some information about these questions can be obtained through the analysis of their arguments. Indeed, it is often the case in the context of schooling that instructors rely on little more than these kinds of written assessments to evaluate learners’ performance. Moreover, formal education relies on the assumption that it is possible to assess students’ learning based on this type of information. Much of the research on argumentation has relied on this same assumption, using the arguments produced by students as a main source of data, supplemented with the direct observation of interactions in the classroom (i.e., dialogues among learners, and
between teachers and learners) (see Newton, Driver, & Osborne, 1999; Sandoval & Reiser, 1997; Zembal-Saul, Munford, Crawford, Friedrichsen, & Land, 2001).

2 Results

2.1 Evolution Module

2.1.1 Caroline and Conrad

The causal structure of Caroline (pseudonym) and Conrad’s (pseudonym) final argument in the Evolution Module is represented in Figure 5.1.

<table>
<thead>
<tr>
<th>a) Why so many finches died in 1977?</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1. Predators</td>
</tr>
<tr>
<td>predator population decreased ⇒ finches population also decreased ⇒ predators cannot be the cause of finches’ population decrease</td>
</tr>
<tr>
<td>#2. Lack of food.</td>
</tr>
<tr>
<td>Decrease in rainfall ⇒ decrease in seeds ⇒ reduced food supply for finches ⇒ many finches died</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>b) Why some finches were able to survive?</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1. Beaks</td>
</tr>
<tr>
<td>bigger beaked finches survived ⇒ Tribulus seeds are bigger ⇒ birds with bigger beaks can better eat Tribulus ⇒ Tribulus is the most prevalent plant on the island during the draught ⇒</td>
</tr>
<tr>
<td>#2. Weight</td>
</tr>
<tr>
<td>heavier birds survived ⇒ there is a positive correlation between food supply and weight ⇒ counter balance ⇒ inconclusive</td>
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<tr>
<td>#3. Wings</td>
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<tr>
<td>birds with longer wings survived ⇒ Not enough evidence</td>
</tr>
<tr>
<td>#4. Legs</td>
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<tr>
<td>birds with longer legs survived ⇒ It’s not likely that it was legs</td>
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Figure 5.1: Representation of the causal sequence of Caroline and Conrad’s written argument for the Evolution Module.
This pair’s written argument indicates that they adopted an exploratory approach, similar to that of scientists like the Grants, observing and investigating trends in various variables in both questions. Notably, their strategy was usually to approach the problem by trying to establish correlations between changes in the variables (i.e., traits) and changes in the environment or the decrease in the finch population. However, Caroline and Conrad did not articulate a complete causal sequence except for one of the explanations. It appears that there is a relationship between being able to establish causal relationships and accepting an explanation. The only explanations that were accepted were those that were well articulated in the sense that they had explicit causal relationships logically connected.

In their final argument, this pair did not consider the possibility of multiple factors acting jointly to produce a certain phenomenon. However, if one looks at how their argument evolved through the module, there is some indication that they initially considered such a possibility. In the second version of the argument, for instance, they label explanations related to two traits (beak length and wing length) as ‘contributing factors.’

The explanations that were well articulated included fundamental domain-specific concepts (e.g., environmental pressure, initial variation, change in frequency of traits, differential survival, relationship between form and function). However, the concept ‘initial variation,’ which is implicit in the notion of change in frequency of traits, was only explicitly integrated into explanations late in the module. In the alternative explanations, although a complete explanation was not articulated, Caroline and Conrad always started their investigations by attempting to establish whether or not there was a change in the frequency of a trait. In these cases, they were not able to establish relationships between form and function that could explain the effect of the selective pressure, but there is evidence that they were approaching the problem using discipline specific strategies.

The fact that only one of their explanations for each of the questions included explicit causal relationships naturally raised the question: ‘What factors kept them from
articulating causal relationships?’ I considered two possible explanations. First, they may have elaborated more on explanations that they intended to accept. Second, they were unable to understand (and articulate) causal relationships for certain explanations, ultimately choosing not to accept them. There is evidence that both ‘causes’ played a role in different circumstances.

In one of the explanations for Question 1, Caroline and Conrad did not address that predators could not account for the death of the finches because their population decreased like the finches’ population. It is possible that they were thinking about the causal relationships involved in their explanation (i.e., predators eat the prey $\Rightarrow$ an increase in predators would lead to decrease in the prey population). Nevertheless, they did not make their reasoning process explicit, and they simply considered the explanation invalid. On the other hand, when investigating the second question, the PTs may have been unable to construct causal relationships, considering the complexity of the factors involved and the limited evidence.

Caroline and Conrad consistently supported their claims with relevant evidence, except in two cases when they did not use evidence. In Question 1, they did not provide evidence showing that seeds served as food for finches. In Question 2, they did not include evidence to support their hypothesis that Tribulus had bigger seeds than the other plants on Daphne Island. However, in the second case, they only “hypothesizing” about this element of the explanation.

The evidence used, like the causal structure of the argument, did reflect principles of knowledge in the domain. For instance, in their explanations for the survival of finches Caroline and Conrad used frequency graphs (better representing change in frequency of traits), they only included adults in the samples (demonstrating an understanding of the variation of traits within the population due to age) and they compared dead and live birds (better representing the concept of differential survival). Although they did not separate males and females, they generated evidence to make a point that the differences between sexes would not be significant in the context of the
problem. This pair also combined evidence from the individual profiles with field notes to demonstrate the occurrence of a relationship between form and function.

One limitation with respect to domain-specific principles became apparent as the evidence was examined: the time frame that PTs used. They compared the populations within a short time period (just before and just after the drought), whereas evolutionary biology focuses on changes over longer periods. This is important because it suggests that changes in the frequency of big beaks was due to the drought or was the result of some other environmental pressure. In addition, Caroline and Conrad did not explore all dimensions of the concept of survival of the fittest, namely, the reproductive aspect (i.e., that offspring of better adapted individuals also have a greater chance of survival). In this case, for instance, it would be important to determine whether the trait (big beaks) was inherited by fledglings born after the drought.

Caroline and Conrad used all types of evidence available in the software environment. For Question 1, they tended to use evidence from the Environmental Window on the characteristics of the environment. This evidence is basically quantitative in nature and was available in the software in a finished form. For Question 2, they always used quantitative representations. When they were able to articulate a complete explanation they also used individual profiles combined with field notes, as well as evidence form the Environmental Window (see Appendix B for a description of the software).

At the beginning of the module, the pair not always provide a description of the evidence, but later they revised pieces of evidence to include a description, as required by the instructor. Individual profiles have annotations with minimal interpretation, solely indicating the beak size of the finch. Caroline and Conrad frequently did something similar with field notes, which had no comments on the behavior per se, and only described the type of beak the bird had, connecting the field note to profile evidence. Notably, in some field notes the pair made a clear interpretation of the meaning of the behavior (e.g., #16, Figure 5.2). Note that these pieces of evidence were used early in the unit, when the PTs were still constructing their explanations, whereas the other field notes
were used as ‘additional evidence’ to further support the explanation constructed based on the two initial field notes (e.g., #16).

In the types of evidence other than field notes and individual profiles, a clear pattern was not identified. In some instances, the pair made explicit the ideas they were constructing based on the tables, and making comparisons between multiple pieces of evidence (e.g., #26, Figure 5.3). More sophisticated interpretations were observed in other pieces of evidence from the Environment Window (e.g., #27, Figure 5.4). However, in these cases, the connections to other pieces of evidence were made explicit only in the justification.

When I examined instances in which graphs were used as evidence, patterns became even harder to discern. In some instances, Caroline and Conrad provided numbers derived from the interpretation of graphs as if these values per se had a meaning. However, they included comparisons between samples when asked to establish a relationship between claim and evidence (i.e., build a justification), like in the case of evidence #27 (Figure 5.4). In other cases, the pair used numbers to explicitly compare values in different groups that were displayed in the graphs (see evidence #26, Figure 5.3). Finally, in other cases, they didn’t mention numbers in the initial description. That is, in the annotation box, the PTs described the evidence by stating their conclusions based on numbers, but the numbers were only mentioned in the justification.

As I discussed earlier, there is a complex (and apparently random) pattern of use of the annotation box, particularly for graphs. However, when annotations were considered in combination with the justification boxes, some coherence in PTs behavior can be inferred. Taken together, these two fields for comments provided a description for a piece of evidence, often connected pieces of evidence to each other, and usually made explicit the claim to which the evidence was connected. Nevertheless, neither in the annotation box in the Data Log nor the justification box in the Explanation Constructor,

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1 What I am calling “sophisticated interpretation” could be defined as “telling the story of the piece of evidence”, that is, making explicit what they were learning from the evidence. In this case, no effort to be solely descriptive would be apparent.
did the pair make explicit the reasoning behind their choice of a certain piece of evidence to support a particular claim (i.e., how a piece of evidence supports a specific claim). The only exception to this pattern relates to evidence #22 (Figure 5.5), in which the PTs made clear how the behavior described in this particular field note supported the claim that smaller beaked finches have difficulty eating *tribulus* seeds. In some instances, Caroline and Conrad only stated the occurrence of a correlation between factors without explaining how that relationship supported their claim. In other cases, the pair referred to a shift in the trait frequency, but did not make explicit the co-occurrence of such a change and the drought, nor did they explain how the shift in frequency related to the claim. Finally, in some cases, the PTs went beyond what the evidence could tell (e.g., #33, Figure 5. 6). Note that in the latter cases, these claims were not included in the explanations.

This lack of coherence in the use of annotation and justification boxes, as well as the redundant use of information when both fields were considered together, was interpreted as indicating that the participants did not make a clear distinction between describing evidence and providing justification.

In the *Galapagos Finches* software environment, PTs were explicitly required to evaluate their explanations [or to think about explanations (Kuhn, 1991)]. Caroline and Conrad used the rating tool in the Explanation Constructor throughout the investigation, applying different categories to different explanations (e.g., accepted with changes, accepted completely). However, at the end of the investigation all of the explanations were classified as accepted completely because they rephrased their explanations using qualifiers and negative words to distinguish the status of each hypothesis (e.g., “not enough evidence,” “not likely,” “not a factor”, “yes”). To justify the choice of a category they always referred back to the evidence they had already presented (e.g., “the evidence shows that”). They did not raise counter arguments or considered limitations in their explanations. That is, the PTs did not produce any record of their thinking about other ways of approaching the problem. Finally, the fact that Caroline and Conrad accepted completely all of the explanations in the final version of their argument led me to infer
that, at the end of the unit, the participants believed it was necessary to demonstrate that they had reached a “final conclusion” in relation to all of the aspects they had explored, and nothing was left open and unresolved.

The pair’s language was concise in all of the explanations, as well as in comments in the annotation and justification boxes. They did not include questions in their explanations, always using affirmative sentences. Questions were kept separate in the Questions section of the Explanation Constructor.

What can the researcher learn about the process Caroline and Conrad went through as they constructed their argument? On the first day, this pair had already identified all of the alternative explanations that they planned to pursue for Question 2, without reaching final conclusions for any of them. In other words, at that point they considered possibilities, leaving answers open. In the following days, they systematically investigated all of the alternatives. Then, they chose one of the explanations and elaborated on it, adding new sub-questions. Most of what was added in the last day referred to this explanation. Throughout the process, they repeatedly rephrased explanations that were initiated earlier in the project.
Figure 5.2: Evidence #16 in Conrad and Caroline’s argument for the Evolution Module. In this case, they interpreted the behavior of not being able to open *tribulus* easily as indicating that the finch did not have a beak long enough.

#16
This finch has a relatively small beak. As a result, it struggles to eat the tribulus. The reason for this is because the tribulus has a hard, spiny cover making it more challenging for the finch to break into it.

Figure 5.3: Evidence #26 in Conrad and Caroline’s argument for the Evolution Module. In this case, they compared the data for *cactus* with the data for other plant species.

26
Cactus population dropped drastically during the drought and was not the most prevalent source of food for the finches.
Figure 5.4: Evidence #27 in Conrad and Caroline’s argument for the Evolution Module. In this case, their description of the evidence is merely a label for the table, without making explicit the interpretation of its significance. It is only in their justification (bottom of the figure) that they interpret the data.
22
The graph showed that the beak length on this bird was not sufficient enough for its survival, which can also be seen in the corresponding field notes where it had a difficult time trying to break the tribulus shell.

Figure 5.5: Evidence #22 in Conrad and Caroline’s argument for the Evolution Module. In this case, the pair explicitly explained how their piece of evidence supported their claim.

33
According to our graphs, this finch has a relatively smaller beak which makes it more difficult for it to eat the tribulus seed.

Figure 5.6: Evidence #33 in Conrad and Caroline’s argument for the Evolution Module. In this case, in their justification, they went beyond what the evidence could support.
2.1.2 Leila and Matt

The causal structure of Leila (pseudonym) and Matt’s (pseudonym) final argument in the Evolution Module is represented in Figure 5.7.

Like the other pair, Leila and Matt pursued multiple explanations to the problem, but one of them was better articulated than the others. Again, the explanation which was most elaborated was the one they accepted. Also similar to the other pair, causal relationships were implicit in the alternative explanation for Question 1 that involved predators. In this case, however, there was evidence that, as Leila and Matt addressed Question 2, they made an effort to explain the changes that occurred in the frequency of various traits. Consequently, the pair approached the problem in different ways, as well as made explicit limitations in their ability to conceive of explanations (i.e., in the wing length explanation).

Also in contrast to Conrad and Caroline, Leila and Matt did not always logically connect components of their explanations to one another. Notably, an important component of the ‘lack of food’ explanation for the death of the finches is left apart in an isolated and poorly articulated explanation (i.e., the drought). This is not an exception. In other instances, they added ideas to their explanations without connecting them to other elements of the explanation, such as initial variation of the traits in their explanation for leg size.

There is no evidence in this pair’s argument that indicated that they considered the possibility that multiple factors could interact to produce the death or survival of finches.
Figure 5.7: Representation of the causal sequence of Leila and Matt’s written argument for the Evolution Module.
In general, Leila and Matt’s explanations were structured around domain specific concepts/principles. In Question 1, they described the selective pressure and how it could lead to the decline in the finch population. In explanation #1 for Question 2, they included concepts such as how form was related to function, differential survival and initial variation. Other explanations for Question 2 were initiated with the investigation of the occurrence of shifts in the frequency of traits, as would be expected in accordance with domain-specific strategies. Notably, they also were able to distinguish among traits that could be directly altered as result of changes in the environment, that is, traits that were not inherited (i.e., weight), and consider this in their explanations.

All of the claims in Leila and Matt’s argument were supported with evidence. Two instances represent an exception: in these cases, they referred to evidence that was available in the software, but did not include it in the explanation. All evidence provided was relevant to the respective claim.

This pair, like Caroline and Conrad, included in their argument the various types of evidence available in the software environment. Graphs were used predominantly in explanations for Question 2, whereas data from the Environmental Window (mostly quantitative) supported explanations for Question 1. In some cases, they combined and related multiple pieces of evidence (sometimes qualitative and quantitative evidence) whenever it was pertinent to support the claim (e.g., various plants that were food for the finches, form of the beak, and behavior of the finches). However, they typically had only a single piece of evidence to support each claim.

The evidence used was, in many aspects, coherent with evolutionary biology strategies and concepts. Frequency graphs were used to support most of the claims for Question 2, except for the trait of weight. I found it particularly interesting that Leila and Matt approached this trait differently from the others, as one that could be affected directly in response to environment changes. Moreover, this pair separated males and females, as well as adults and fledglings, which demonstrated some understanding of the variability in the population. Finally, they combined individual profiles and field notes to document the relationship between form and function for beaks. Nevertheless, the PTs
did not compare dead and alive finches in these graphs. They compared only birds that were alive from the season before and after the drought. Implicit in this approach is information about the traits of birds that did not survive the drought, and consequently, a change in the frequency of a trait. However, it would have been more appropriate to directly show the data on survivors versus dead birds for each of the seasons, to make clear the point of differential survival.

As one can infer from that observation, like the other pair, Leila and Matt did not use the appropriate time frame to identify shifts in the population. Furthermore, they did not make any distinctions between the annotation box and justification box, writing the same in both. Nevertheless, these annotations were very rich in the sense that PTs presented their ideas as they examined evidence. Leila and Matt included in their annotations the major lesson(s) learned from the evidence (e.g., #10, Figure 5.8). In these instances, contrary to what happened to the other pair, no mention to numbers was made, merely a general conclusion (i.e., main ideas) was presented. This pair also used the comments on the annotation box to relate particular pieces of evidence to others (e.g., #20, Figure 5.9). However, the most interesting aspect of their annotations was that they recorded questions, wonderings, and hypotheses that could be related to a certain piece of evidence (e.g., #1, Figure 5.10).

Like the other pair, in no instance did Leila and Matt establish an explicit relationship between the evidence and the claims. Usually their comments referred solely to what the evidence might tell them, not exactly to how/why it would tell that. In other words, they did not include justification in their explanations.

Leila and Matt used the rating tool throughout the investigation but only for some of the explanations. Similar to Caroline and Conrad, they tended to completely accept their explanations, relying on the evidence previously presented. However, it is worth paying attention to some exceptions. In one case, instead of using evidence to justify their choice of how to explain the lack of rainfall, the pair argued that there was no alternative explanation to a drought. Although this particular explanation is very limited, it represents a unique explanation with respect to the way it is evaluated. Both pairs, in
general, did not evaluate their explanations in the context of alternative explanations that were generated, but examined them individually. In this particular case, in my interpretation, that type of evaluation was occurring.

A second exception was the use of the category *accepted with changes* for the explanation that predators were not responsible for the decrease in the finch population. Earlier in the module, the participants had *accepted completely* this explanation, stating that there were no other predators. However, in their final argument, they noted that there might be other predators, and without being sure of that, one could not discard the possibility of predators (other than the owls) being responsible for finches’ death.

Finally, in one of the explanations (i.e., survival was probably not related to wing length) PTs used qualifiers and justified that they reached that conclusion because, although a change in the frequency of the trait ‘long wings’ was observed, they were not able to explain how this trait would be advantageous; thus, the observation lost its significance. In this case, notably, the participants identified limitations in their own ability to generate explanations and used these limitations as part of the rationale for constructing the explanation.

The language Leila and Matt used to construct their argument is different from Caroline and Conrad in the sense that they used a more “spontaneous” language, including questions in their explanations and sometimes making explicit questions/wonderings that led them to investigate something or to follow a certain path. A good example is the explanation “not because of beaks,” constructed on the day they started the written argument. As noted, this kind of language is consistently used in their annotations. This spontaneity also could be illustrated by the use of an explanation point in one of their comments for a piece of evidence. Does it represent an expression of emotion, excitement in face of a finding, or simply emphasis? This is a question I will have to leave open.

The process Leila and Matt went through to construct their argument was quite different from that of the other pair. They initially explored only two alternative
explanations for Question 2 (i.e., beak length and weight). Then, on the last day of the investigation, they added two more alternative explanations (i.e., leg and wing length).

An interesting aspect that occurred with Leila and Matt was that they changed their minds about the “beak explanation” as the investigation proceeded. In the first version of their argument, using scatter plots, they concluded that the finches’ survival was “not because of the beaks” (e.g., evidence #4, Figure 5.11). Later, beaks turned out to be the most robust explanation for why birds survived. Notably, the pair did not keep a record of how and why their position changed. They simply deleted their initial explanation “not because of the beaks,” and adopted “the birds who [sic!] survived had bigger beaks.” Thus, the process of argument building was not made transparent. In my opinion, that is contradictory with the fact that this pair apparently was making more transparent various elements of their thinking (questions, wonderings, limitations).

2.1.3 Summary for the Evolution Module

Both pairs demonstrated robust understandings of subject matter, using appropriately both discipline-specific concepts and strategies, except for the effects on the offspring and the time frame used. Both pairs constructed arguments that were consistently supported by evidence, exploring multiple explanations. However, neither of these pairs included justifications in their explanations, focusing instead on describing evidence. Both pairs accepted completely one of the explanations (the one that they could best articulate) and omitted attention to limitations and counter-arguments to this explanation. Although, at the end of the module PTs were considerably unambiguous and decisive about a chosen explanation, throughout the module they changed and revised their arguments to some extent. Interestingly, the pair that had the most coherently structured argument (Caroline and Conrad) did not make as explicit their ideas, questions and wonderings as the other did (Leila and Matt).
Figure 5.8: Evidence #10 in Leila and Matt’s argument for the Evolution Module. This example illustrates how in the *annotation box* the pair included an explicit interpretation of data.

Figure 5.9: Evidence #20 in Leila and Matt’s argument for the Evolution Module. In this case, PTs related the *field note* to other pieces of evidence.
Figure 5.10: Evidence #1 in Leila and Matt’s argument for the Evolution Module. In this case, the pair included a question in their description of evidence.

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Figure 5.11: Evidence #4 in Leila and Matt’s argument for the Evolution Module. This piece of evidence, constructed earlier in the investigation reflects how the pair, at first, did not align with the explanation they chose to accept at the end.
2.2  Light Module

In this module, for both pairs, the structure of the argument was quite different from that of the Evolution Module. In the process of learning about light, instead of explaining a complex phenomenon/event, PTs used various phenomena as evidence to support generalizations about the nature of light. As noted in the Context Chapter, instead of responding to the question “Why do we see what we see?” PTs were instructed to respond to the question “What happens to light?” which shifted the focus of the argument to producing such generalizations.

2.2.1  Caroline and Conrad

The causal structure of Caroline and Conrad’s final argument in the Light Module is represented in Figure 5.12.

When examined individually, the claims in Caroline and Conrad’s argument had logically connected components. However, in spite of their attempts to establish relationships between the various claims, they were not successful in making these connections. As instructors, we predicted that it would be difficult for PTs to connect the generalizations that constituted their argument to the guiding question, “Why do we see what we see?” mainly because of the lack of evidence associated with sight. To make further connections between the nature of light and the capacity to see appears to be impossible based solely on participants’ knowledge about light. Consequently, the statements associated with that question were still disconnected at the end of the module.

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2 Although Caroline and Conrad were not asked to write a response to the question “Why do we see what we see?” which would require them to explain the phenomenon of sight, they constructed a summary of their explanation trying to connect it back to the driving question.
a) Claims

#1. *Light is reflected*
- a white paper when held close to a red paper turned red ⇒ light can be detected coming from a paper ⇒ light is reflected

#2. *Light travels in straight lines.*
- the image of a candle in a screen is upside down ⇒ if we move the screen, the image becomes bigger and fainter or smaller and more distinct ⇒ light travels in straight line

#3. *Light reflects at the same angle when it hits a mirror*
- in a flat mirror, a light beam reflects in an angle that equals the angle of incidence ⇒ in convex and concave mirrors light beams reflected back through the focal point parallel to the reference line ⇒ light reflects at the same angle when it hits a mirror

#4. *Light is refracted toward or away from a perpendicular reference line based on the density of the material it travels through*
- in a glass plate, light bends towards the reference line when it enters the plate, and away from it when exiting the plate ⇒ the same occurs with lenses ⇒ positioning and combining lenses indifferent ways leads to the formation of different types of images (i.e., big/small; upright/inverted) ⇒ light refracts

b) Why do we see what we see?
- materials reflect light differently ⇒ light travels in straight line ⇒ it can enter our eyes and form images
- we see what we see in mirrors because light reflects in the same angle
- the type of lenses determine what kind of image we see (i.e., upright/inverted or enlarged/reduced)

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Figure 5.12: The structure of Caroline and Conrad’s written argument for the Light Module.
This pair did not explore alternative explanations for the phenomena or counter arguments for their generalizations. For instance, for the claim “light travels in straight lines,” the instructor explored an alternative explanation for the phenomenon in class that was observed by PTs. Even so, alternative explanations were not included in the argument. Caroline and Conrad supported all of their claims with relevant evidence, which was described in detail and included some of the procedures used to obtain it. All of the evidence used was derived from experiments conducted in the course. In their justifications, the pair tended to restate the evidence instead of elaborating on their assumptions and explaining the relationship between claim and evidence. Two of the justifications for their claim “Light refracts” represent exceptions (Figure 5.13), since in these claims they made explicit their assumptions and connected the evidence to claim. No evaluation of explanations or discussion of possible limitations was included as part of the arguments. Like in other modules, they used a very ‘neutral’ and direct language.

How did Caroline and Conrad’s argument change over time in this module? In the first version, their argument had various claims that were more extensive, usually already supported with evidence (Figure 5.14, Claim 2 version 1). As I inferred from this and another example, they frequently tried to establish connections between the driving question and their claims. Accordingly, in the justification, these connections were explained as far as possible (see previous example, Figure 5.3). In the final version, their connections were reduced in their claims to only those that could be supported with evidence. However, in general their argument underwent little change: they tended to use the same pieces of evidence and justification, adding only one new claim. Note that their explanations were not systematically revised as much as explanations in the previous module, only their form was altered.

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3 The first version was constructed before the major intervention of the coordinator of the course in this module. In the intervention, she explained how the instructors expected PTs to articulate claims, how to support each aspect of their explanations with evidence, and what ‘justification’ was.
JUSTIFICATION 1:
The glass plate experiment supports our claim because glass is more dense than air and the beam bent toward the perpendicular reference line. Similarly the beam bent away from the perpendicular reference line when exiting the plate because air is less dense than glass.

JUSTIFICATION 2:
The lens experiment supports our claim because the glass lenses are more dense than the air, so the light beams bent toward the perpendicular reference line when going from air into glass. Conversely it bent away from the reference line when going from glass into air.

Figure 5.13: Two justifications constructed for supporting the claim “Light refracts” in Caroline and Conrad’s final argument for the Light Module. In this case, their assumptions were made explicit.

CLAIM 2: We see what we see because light travels in straight lines and certain rays of light are angled in a way that allows them to travel into our eye through our pupil and forms an inverted image.

EVIDENCE: Pin Hole Experiment
-We first made a prediction of what we would see on the screen behind the paper with a hole in it when the candle was lit. Then, we lit the candle and moved either the screens or the candle back and forth in order to view the different images produced.

-The image was an upside-down candle flame. When we moved the screens further apart or the candle closer, the image got bigger and fainter. When we moved the candle back or the screens closer together, the image got smaller and more distinct.

JUSTIFICATION:
Light rays travel in straight lines, in every direction, from every point. Only certain rays were at the right angle to pass through the hole, which produced the upside-down image. For example, light that traveled from the top of the candle came out in every direction, but only the ray with the right angle to fit through the pin hole was able to be seen on the screen. The top ray was seen on the bottom of the image, while the bottom ray was seen at the top of the image, therefore making the image appear upside-down. The pin hole represents the pupil on an eye, and the screen represents the back of the eye, or the retina. What we see shows up as an upside-down image on the retina of our eyes.

Figure 5.14: Content of one Explanation Page in the initial version of Caroline and Conrad’s argument in the Light Module. This claim was more extensive and established clear relationships with the driving question.
2.2.2 Leila and Matt

The structure of Leila and Matt’s final argument in the Light Module is represented in Figure 5.15.

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a) Claims

#1. We see the light that is reflected off objects. Some light is reflected more than others, while other light [is] (sic!) absorbed. This allows us to see objects in different shades.

- we observed light reflecting off a colored piece of paper onto white paper ⇒ the light sensor measured how much light was reflected ⇒ light is reflected and what is not reflected is absorbed

#2. Light travels in a straight line and reflects off objects at all angles. Light also leaves the source at all angles as well.

- using mirrors, beams of light reflected back at the same angle it entered ⇒ the beam was shining in a straight line ⇒ light travels in straight line

#3. A. Just like we see reflected light, we also see refracted, or bent, light.

- the direction of the beam of light was altered by lenses ⇒ in convex lenses the beam exits the lens heading away from the focal point and in concave lenses it angles towards the focal point ⇒ “light is refractable and is able to be seen” (sic!).

B. Refracted light will meet at some point to produce a clear image to the viewer.

- we used lenses to project images in a screen ⇒ depending on lenses used (concave or convex) the position and size of the image varies ⇒ the focal point is the place where all light that enters perpendicular to the lens is refracted to ⇒ all light will meet at one point, producing a clear image.

#4. Light can also be absorbed

- in a glass plate, light bends towards the reference line when it enters the plate, and away from it when exiting the plate ⇒ the same occurs with lenses ⇒ positioning and combining lenses indifferent ways leads to the formation of different types of images ⇒ light refracts

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Figure 5.15: The structure of Leila and Matt’s written argument for the Light Module.
Leila and Matt’s argument has a series of limitations in its structure. Notably, they addressed the same claim twice providing similar evidence to support it. Such repetition is taken as an indication that this pair did not revise their argument to make sure it held together, since this particular problem could be easily identified. Another problem was that sometimes they constructed tautological explanations. For instance, they stated that light reflects because it was observed reflecting from the construction paper (Claim 1). In other words, in my interpretation, they were stating that light reflects because it reflected.

In their claims, they included many aspects that they could not support with evidence and/or combined aspects in the same claim in such a way that supporting them with evidence became more complex and challenging. For instance, in Claim 2 (Figure 5.16) Leila and Matt included multiple elements in the same claim (i.e., straight line plus reflecting at all angles) that could not be supported with the same piece of evidence using the same justification. Some of the instances of lack of support with evidence occurred when they tried to relate the guiding question “Why do we see what we see?” In other cases, evidence was described in a very superficial manner, and it did not support the claim (e.g., Claim 2; Figure 5.16). The researcher wonders if, in this case, they were unable to further describe the evidence due to limitations in their subject matter knowledge. In other instances, this pair included pieces of evidence in the justification. Their description under evidence was typically restricted to the procedures they adopted to make the observations plus part of the results, whereas the remainder of the results was fully presented in the justification box. In other cases, they separated evidence and justification, making explicit their assumptions under justification. It is interesting how it is through the expression of these assumptions that limitations in their subject matter knowledge emerged clearly. Claim 2 represents an illustrative example of this type of problem (Figure 5.16).

Like the other pair, Leila and Matt did not evaluate their explanations. Moreover, contrary to the previous module, they did not include questions or considerations about what lessons they learned from the evidence.
In the initial version of their argument, Leila and Matt included elements that clearly related to the guiding question “why do we see what we see” (e.g., connections with pupil). They not only changed their explanation, separating it into multiple claims and trying to eliminate ‘connections’ to the guiding questions, but they also eliminated evidence that was used in the first version (e.g., evidence 1, Figure 5.17). Used as an example, this was a relevant piece of evidence that was not used in the final version. It is difficult for the researcher to speculate about what motivated the pair to eliminate this piece of evidence; however, it may be related to the lack of subject matter knowledge to justify its use.

2.2.3 Summary of Light Module

In my interpretation, the major changes in participants’ arguments involved changing the claims to make them more focused and concise. Caroline and Conrad were able to successfully revise their claims, whereas Leila and Matt were not. However, both pairs struggled with establishing connections between the various claims they constructed. Caroline and Conrad were more invested in this effort than the other pair.

All of the evidence used to support participants’ claims came from classroom experiments. To separate evidence and justification was difficult for both pairs, but at least somewhere in their explanations, connections between claims and evidence were included as part of the argument.

Another important trend was that in this module there was no mention of alternative explanations or even alternative interpretations of evidence.
Figure 5.16: Explanation page in the second version of Leila and Matt’s light argument. It shows how they included multiple elements in their claims, and how evidence was described in a superficial manner. In this case, limitations in their subject matter knowledge became clearer as they constructed the justification.

CLAIM2
Light travels in a straight line and reflects off objects at all angles. Light also leaves the source at all angles as well.

EVIDENCE
The Mirror Lab. In this experiment, we reflected beams of light off of mirrors, observing how light always reflected back at the same angle it entered. This all occurred [sic] with the beam shining in a straight line.

JUSTIFICATION
This evidence supports our claim that light travels in a straight line. Just by looking at the picture it is easy to identify each separate beam as it heads directly from the source to the mirror. This experiment also shows how light, while reflected at the same angle it enters an object, reflects from all angles of an object. By having light reflected in a straight line from all angles of an object, it ensures that light from same angle will eventually reach our eyes and allow us to see it.

Figure 5.17: Description of evidence that was presented in the initial version of Leila and Matt’s light argument. It was eliminated in the final version of their argument.

EVIDENCE:
The Pinhole/Candle Lab is an experiment performed in which a sheet of paper, containing a small pinhole is placed between a lit candle and a blank sheet of paper. We then observe the light from the candle pass through the pinhole and onto the blank sheet of paper. On the blank sheet of paper, we see an upside down image of the candle flame. This occurs because only certain angles of light were allowed to pass through the hole. Thus, the top of the image went to the bottom, and the bottom went to the top.
2.3 Global Climate Change Module

2.3.1 Caroline and Conrad

The structure of Caroline and Conrad’s final argument in the Global Climate Change Module is represented in Figure 5.18.

Their argument was well structured, it addressed all of the sub-questions posed, and the components of each explanation were logically connected. However, they did not explore multiple possible explanations/perspectives on the issues of Global Climate Change. Moreover, they did not consider how multiple factors could act jointly to produce changes.

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**a) Claims**

#1. *There was a significant increase in global temperatures*
  - the global temperatures vary in regular patterns following natural cycles ⇒ there was no increase of about 1 C in the past 100 years ⇒ this increase rate is faster than normal ⇒ increasing is significant

#2. *Carbon dioxide levels in the atmosphere cause changes in global temperatures*
  - temperatures are higher with the presence of an atmosphere ⇒ there is a positive correlation between concentration of CO2 in the atmosphere and global temperatures ⇒ carbon dioxide levels in the atmosphere causes changes in global temperatures

#3. *Human activity is causing changes in global temperature*
  - the higher the amount of industries, the more CO2 is emitted ⇒ the denser the population the more CO2 is emitted ⇒ Human activity is causing changes in global temperature

#4. *Consequences of global warming*
  - increase of temperature will occur in areas that currently are below 32 F ⇒ above 32 F ice melts ⇒ areas with ice may melt
  - temperatures will change ⇒ temperature affect the distribution of vegetation ⇒ vegetation may shift

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Figure 5.18: The structure of Caroline and Conrad’s written argument for the Global Climate Change Module.
Caroline and Conrad supported all of their claims with relevant evidence, usually providing more than one piece of evidence for each claim. They did not use experimental evidence to support their claims, only graphs and visualizations. In some cases, they appropriately used concepts of the field of Geosciences, contrasting different time scales to draw conclusions about temperature change (see claims related to the question, “Are there signs that a significant change in temperature is occurring?” Figure 5.19). Nevertheless, their claims were not always thoroughly supported with evidence (e.g., when they referred to the occurrence of natural cycles of temperature variation). In this case, they only addressed the occurrence of a correlation between temperature and CO₂ concentrations in the justification. In a second instance, when they predicted that vegetation could be affected by changes in global temperatures, they did not discuss the evidence at all. Rather, they simply provided a title for the visualization they used as evidence. Here, the problem may be that this map *per se* does not provide enough evidence for one to reach a conclusion. That is, further information is necessary. Thus, in this instance, the pair would have had to establish relationships between temperature and distribution of vegetation (like they did for the icy regions), involving a more complex conceptual framework and a more robust understanding of the subject matter.

In their justifications, Caroline and Conrad usually made their assumptions clear and connected them back to their claim (e.g., “what would be the consequences of global warming? – ice melting). Note that at any point, both in their justification and in their description of evidence, the pair introduced questions and wonderings. Additionally, possible limitations of their explanations were never addressed or considered, and no reference to possible alternative explanations was made.
Are there signs that a significant change in temperature is occurring?

A significant rise in temperature is occurring.

**EVIDENCE:**
This graph on the left shows that there has been an increase of about 1 degree Celsius over the past 100 years.
**JUSTIFICATION:** Justification (Left): This graph supports our claim since it shows that temperatures have risen over the past 100 years.

**EVIDENCE:** The graph on the right shows that there have been patterns of increasing and decreasing temperatures over the past 150,000 years.
**JUSTIFICATION:** (Right): This graph supports our claim because it shows that the increases in recent years are significantly larger than those of the past.

**GENERAL JUSTIFICATION**
If you just look at one or the other of the graphs, then you could have contradictory results. However, after closer examination, you can see that the 1 degree increase over the last 100 years is a much faster rate than has occurred recently. An increase of this magnitude has not been seen over the past 10,000 years. Thus, temperatures are increasing significantly.

Our claim relates to the driving question, "Are global temperatures increasing?"... because... the graphs show that the temperature has not only increased in recent years, but also has increased more dramatically than in the past.

Figure 5.19: Explanation page for Caroline and Conrad’s climate change argument. In this case, they contrasted two different time scales to draw conclusions about temperature change.
2.3.2 Leila and Matt

The structure of Leila and Matt’s final argument in the Global Climate Module is represented in Figure 5.20.

<table>
<thead>
<tr>
<th>a) Claims</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1. [Global] temperatures increased more than normal</td>
</tr>
<tr>
<td>• temperature increased 1 °C in the last century ⇒ normally, the increase is about 68 °C in 960 centuries ⇒ temperatures increased more than normal</td>
</tr>
<tr>
<td>#2. The denser the atmosphere causes temperatures to increase</td>
</tr>
<tr>
<td>• the Earth without atmosphere would be much colder ⇒ The denser the atmosphere causes temperatures to increase</td>
</tr>
</tbody>
</table>

Carbon dioxide causes temperature to increase.
• in an experiment two bottles one with greater concentration of CO₂ than the other were heated ⇒ in one of the groups the bottle with CO₂ heated faster in the other it did not ⇒ the second group made a mistake ⇒ carbon dioxide causes temperature to increase |

#3. A. Industrialized nations emit more CO₂ than unindustrialized nations |
• regions that emit more CO₂ are industrialized regions |

B. Population density is not a viable indicator of CO₂. |
• regions with denser populations are not necessarily the regions with higher CO₂ emissions ⇒ Population density is not a viable indicator of CO₂ |

#4. Global warming causes the temperature to increase |
• Earth becomes warmer as more CO₂ is added to the atmosphere ⇒ some regions that are now under 32 °F will be over 32 °F ⇒ ice would melt |

Figure 5.20: The structure of Leila and Matt’s written argument for the Global Climate Change Module.
In most of the cases, when analyzed individually, explanations had causal relationships logically connected. However, often the claims did not involve a level of generalization that would permit establishing a clear connection with questions and/or would not demand the elaboration of a series of assumptions. The claims in response to Question 3 represent illustrative examples of such limitations. Their claims were so specific that the lessons learned in the context of the problem being investigated (e.g., humans are in part responsible for the raise in global temperatures) were not clear. In other words, although they related industries to CO\textsubscript{2} production, Leila and Matt did not relate CO\textsubscript{2} production back to global warming. Consequently, their findings were presented without articulation of their significance to the issue of global warming. In a second example, the pair’s claim stated, “global warming would cause temperatures to increase,” which is implied in the definition of global warming. Thus, this is an example of a tautological statement (i.e., global warming causes global warming, Figure 5.21). Only as part of their justification did they make explicit a consequence of global warming. That is, that ice would melt in certain regions of the world.

Leila and Matt supported their claims with relevant evidence, including in their argument all the types of evidence generated in class in the module. Sometimes descriptions of evidence were not detailed enough, and frequently they were included as part of the justification. For instance, when arguing that population density would not be a good indicator of CO\textsubscript{2} emissions, they did not give specific examples, but simply provided a general description of the evidence (Figure 5.22). The way Leila and Matt used evidence also was interpreted as indicating limitations in their understandings of discipline-specific strategies. For instance, they provided two pieces of evidence to support their claim that “Temperatures are increasing more than normal”: a graph showing how much the temperature had increased in the last century and a graph showing cycles of temperature change in a period of many thousands of years (Figure 5.23). Apparently, they recognized the interdependence of these pieces of evidence (see justification for Claim 1; Figure 5.23). However, the evidence on larger scale cycles was not thoroughly discussed or connected to the claim (Figure 5.23). In this case, the
challenge for learners was to work with representations of data reflecting different time scales. This is an important element that characterizes studies in the field of Earth Sciences (Ault Jr., 1998).

Leila and Matt, regularly made their assumptions explicit in the justifications, connecting evidence back to the claim (e.g., claim “a denser atmosphere causes temperatures to increase”). Exceptions occurred occasionally. The claim discussed earlier on cycles across thousands of years is a good example of how they did not articulate assumptions. I hypothesize that it may be because they provided little description of a piece of evidence, maybe because of lack of subject matter knowledge.

Like the other pair, no explicit evaluation of their own explanations was included in their argument for the Global Climate Change model. However, Leila and Matt did point out contradictions that emerged in the process of investigation (though not systematically exploring them). For instance, they noted that there was contradictory evidence – some going against their own claim, some supporting it – with respect to the effects of CO₂ concentrations on increasing temperatures. The experimental evidence obtained in class indicated both that there was an effect and that there was not. Moreover, this pair included in the description of one piece of evidence a question that apparently derived from examination of this evidence. As the pair worked to support a claim on how industrial activity was related to the emission of CO₂, they posed the question, “Is population factor correlated with high CO₂ levels?” Later the pair investigated this question and obtained evidence that went against the intuitive notion that population density would always be positively correlated to CO₂ emissions (Figure 5.22). Interestingly, the other pair did not reach the same (and more accurate) conclusion.

4 Note that these contradictions were not explored as a whole class as the instructor was expecting that learners would take the initiative to bring this problem to discussion.
What are the consequences of global warming?
Global warming causes the temperature to increase.

Evidence
The graph on the left shows the average temperature with an increase in CO2. The graph on the right shows the predicted temperature without considering increases in CO2.

Justification
This evidence supports our claim because it shows that the Earth becomes warmer as more CO2 is added to the atmosphere. Some areas will be greatly affected by such an increase. Lake Onega, for example, is predicted to be under 32 degrees without a CO2 increase, but over 32 degrees with an increase. Therefore, the ice in Lake Onega will melt, causing water levels to rise.

Our claim relates to the driving question (specify which driving question)... because...it demonstrates that CO2 levels have an effect on temperature.

Does population density contribute to CO₂ emissions [sic]??
Population density is not a viable indicator of CO₂ levels.

Evidence
This graph shows the spread of population across the globe. The red and orange regions show the regions of highest population while the blue regions show the areas of lowest population.

Justification
This graph justifies our claim in that the regions with highest population aren't necessarily the same regions with high CO₂ emissions [sic!]. For example, the United States has very high CO₂ levels but they don't have one of the higher populations. Therefore, population is not always a strong indicator of high CO₂ emission [sic!].

Our claim relates to the driving question (specify which driving question)... because...the driving question is “what causes global warming?” and we stated in our previous explanation page that CO₂ plays a role. We now see that population density does not correlate (always) with high CO₂ emission [sic!].

Figure 5.21: Explanation Page from Leila and Matt’s argument in Global Climate Change Module. In this case, their claim is tautological but they further clarified their ideas in the justification.

Figure 5.22: Explanation Page from Leila and Matt’s argument in Global Climate Change Module. In this case, they only provided a general description of evidence without specific examples.
Are global temperatures increasing?
We believe that global temperatures are increasing at a faster rate today.

This graph was discussed in class, compliments of Danusa. –(BLACK GRAPH INCREASE IN THE CENTURY)

Evidence
This evidence shows that over the course of a century, our mean temperature has increased by one degree Celsius.

Justification
In class, we learned that temperature increased at a mean rate of 6.8 degrees over a period of 960 centuries (960,000 years). That factors out to a growth of less than one degree per century. According to the century graph, we are currently increasing at a rate of 1 degree per century. Clearly, we are increasing a much more intense rate than before.

Our claim relates to the driving question (specify which driving question)... because...it shows that temperatures are increasing more intensely and there must be a reason for this.

Are global temperatures increasing? Part II
We believe global temperatures are gradually increasing.

Evidence
TEMPERATURE GRAPH FOR TOUSANDS OF YEARS
This evidence shows the natural patterns of global temperature increase as seen over 960,000 years.

Justification
This supports our claim that temperature is gradually increasing over time. Therefore, if temperature has been steadily increasing for 960,000 years then there is reason to believe that this is still occurring today.

Our claim relates to the driving question (specify which driving question)... because...it shows temperature increase.

Figure 5.23: Content of Explanations Pages for the first claim in Leila and Matt’s argument for the Global Climate Change Module.
2.3.3 Summary of Global Climate Change Module

In this module, both pairs consistently supported their claims with evidence. They still experienced difficulty separating evidence and justification, but there was some progress in this direction. PTs also struggled with integrating multiple pieces of evidence in a single explanation, an important aspect of the module. One pair was more successful in such an integration, however, both were able to integrate evidence representing different time scales to respond to the problem. This ability reflected the use of discipline-specific strategies to construct their arguments.

Notably, neither of the pairs explored more than one explanation as part of their argument, although they were exposed to two points of view on the issue from the very beginning of the module.

3 Trends across Modules

Comparing the arguments that the two pairs constructed across the modules, I noted first, that evidence was used to support claims consistently in all the three modules. Second, there was a development in terms of being able to better characterize pieces of evidence, as well as to make explicit assumptions in the justification. That is particularly notable for Caroline and Conrad, because in my interpretation, in the first module they tried to avoid making interpretations when describing the evidence. However, some limitations persisted until the end of the course. The analysis of their arguments indicated that, first, to separate evidence and justification was a continuous challenge, since both pairs frequently included part of the evidence in the justification. Interestingly, after the first module, they did not do the opposite, that is, include assumptions and connections to the claim in their description of evidence. Second, only in the Evolution Module did PTs consider multiple explanations. Third, also only in this first module did participants evaluate their own explanations. Usually the participants did not think about their arguments. They tended not to generate counter arguments or to recognize explicitly limitations. Moreover, at no point did they attempt to evaluate
explanations or consider them in the context of possible (i.e., alternative) explanations. Typically, they relied on evidence already presented to evaluate their explanations.

If I was to point out major aspects that distinguish the two pairs I would mention that, on one hand, Caroline and Conrad were able to construct well-structured arguments, following systematic and organized paths, demonstrating solid subject matter knowledge. They also frequently revised their arguments and reconsidered their ideas in a way that the final argument was considerably coherent and cohesive. They pursued such a coherence and cohesion even when not required to, like in the Light Module, when they constructed a page ‘putting together’ all their claims. On the other hand, Leila and Matt included questions and wonderings in their arguments, they pointed out contradictions, they pursued questions, they used their own language, particularly, in the first module. This is even more interesting considering that their arguments, in general, were not as logically structured, had fewer pieces of evidence and contained some contradictions, compared to those of Caroline and Conrad. For me, that indicates that this pair was engaging the process of argument construction in a more “authentic” manner, in the sense that they included aspects that were personally relevant for them because they emerged ‘naturally’ from their investigation. In certain instances, this attitude appears to have worked in their favor. In the last module, for example, as they investigated population density they were able to learn about aspects that others did not. Moreover, they implicitly identified possible limitations in their explanations, creating a potential space for further investigation, and, thus, further learning.

As instructors, the SCIED team (including myself) considered these PTs good learners and all of them got A’s in the course. What happened as the researcher revisited the same arguments that were evaluated in the context of the present study? To what extent did ‘researcher’ and ‘instructor’ agree? Some limitations in participants’ knowledge of the subject matter, as well as their knowledge about argumentation, certainly surfaced. Moreover, I was able to identify aspects of the SCIED 410 context that fostered improvement upon some of these limitations, as well as others that could hinder such a development. Still, the researcher would say that both pairs were
successful in building and using arguments in science learning in the course. Considering these findings in light of the goals of science education reform, one could say that learners came to be relatively proficient in the practices and discourse of science (at least in those that were the focus of the course). In addition, one could argue that since they knew how to do and how to use these practices that these PTs did learn science, and argumentation was a key aspect in this process. The question that surfaced at that point was: “Would the PTs that participated in this study agree with the researcher?” Then, one comes to the realization that there is not enough evidence to say that the process of constructing arguments was important for their learning of science from the learners’ perspective. Moreover, as will become clearer in the following chapters, there is not enough evidence to say that they learned science argumentation and science.

4 Final Remarks: Behavior and Meaning

The analysis of arguments when conducted in an isolated manner involves looking at behavior out of the context of meaning that participants attribute to it. In other words, the researcher is imposing her meanings to participants’ behavior. The researcher makes an effort to distance herself from the participants and focus on the rubric (i.e., theoretical constructs derived from the literature). From the mere ‘observation’ of behavior, many specific questions emerged. For instance, What was going on when PTs did not separate justification and evidence? Why did PTs tend not to pursue multiple explanations? How was building the argument helpful to learning about natural selection? However, underlying these specific questions, there are also major questions to be answered. First, if seen from another perspective, would behavior be described and understood differently? Second, why did people behave the way they did? What meanings do these people attribute to that behavior? Third, how do participants feel about the experience? These questions indicate that maybe a more “complete” assessment (and understanding) of the stories of our participants could not be derived solely from “argument analysis” (or even a more ‘complete’ analysis of PTs’ behavior).
Maybe this is the only ‘viable’ way to assess students in a classroom in the school system, but should researchers rely on the same assumptions that educators do? In times when accountability is so valued, educational researchers must raise serious questions. Are there differences and nuances that are not captured by the ‘traditional’ assessment? Would it be valuable to go further and investigate questions such as those posed previously? What picture would emerge from this investigation? What would be gained from such a different knowledge?

Interestingly, as a researcher, I didn’t need to know more about the context of research and the participants than what the reader knows in order to analyze the arguments and draw conclusions. I could infer a series of explanations for behaviors based solely on a few pieces of information available about the participants. The only thing I would have to use was some basic information (e.g., major). This did not actually occur, since I interviewed the participants, but it could have been like that (it has been like that). I did not need to take into consideration ‘who these people were,’ meaning that this aspect would not necessarily inform my conclusions. Without taking into consideration the meaning of the experiences for participants, a researcher is left with inferences about their behavior that are constructed solely on theoretical constructs. The person(s) who participate in the study become of secondary significance, they are understood only as they are placed in certain categories (e.g., adult, male, white, science major).

In the next chapter, I will try to represent two types of shifts. First, there was a shift in my thinking about participants (and their experiences). What happens when I start to pay attention to people? More importantly, what happens when I start to look not only at people’s behavior, but also to the significance people give to what they do and to their experience? Second, there was a shift in perspectives on leaning – which is directly related to the first shift. Can we say that learning occurs based solely on performance on tasks that demonstrate the acquisition of knowledge about ways of thinking (e.g., engaging in argumentation) or concepts (e.g., differential survival, light travels in straight line)?
Chapter 6
From Objects to People: Learning about Participants

1 Introduction

In this chapter, I discuss my understanding of the participants in this study. As mentioned in the previous chapter, my focus on this aspect represents a change in the direction and perspectives of my research. There is no doubt that at the initial stage, I had an interest in participants’ perceptions, however, I later wondered what my understandings of these perceptions were. At the beginning, I still believed that through people’s behavior *per se* (in class, at home, at work, with their families, friends or instructors, in the past, and at the present), I would construct my understandings of their experiences. Although this was not written anywhere in my proposal, the way I went about collecting and analyzing data reflected much of this approach. For instance, in the interviews, I tended to focus solely on what had happened, instead of on the significance of experiences to people and the feelings that emerged from those experiences. Only at the later stages of the research, when I had an opportunity to really focus on who these people were, did the meanings that people construct and where they come from become central to me.

In this chapter, I invite the reader to engage in the experience of turning to *people*, hoping that he/she learns as much as I did. I provide a profile of each of the participants, including impressions about science and experiences in science learning.
2 The Participants

2.1 Leila: “Science Brings a Bad Taste to my Mouth”, “I don’t drink in the same cup”

Leila was a 19-year-old Italian-American young woman. She was in her first semester at college, majoring in Spanish Secondary Education. Leila was taking 18 credits during the semester that she was enrolled in SCIED410. She described the semester as very busy and overwhelming. If I, as instructor and as researcher, was to describe Leila based on the short period of few months that we worked together, I would describe her as an enthusiastic young woman, full of energy and emotion. As a student, even when she described herself as tired, not motivated, not engaged and shut-off, in class I saw her as one who would make an effort to pose questions or give her opinion. She would laugh and talk, rather than sleep. She would run to a class of which she was not particularly fond. As a participant, she shared her experiences, and communicated her feelings about them. Gradually, she became more direct about her criticism to the course as well as about the process she was going through – sharing her stories, difficulties and challenges that she faced, as well as her accomplishments.

Leila came from a middle-class family. She had two brothers: an older one, 25 years old, and a younger one, 10 years old. “I learned so much from seeing him grow up,” recalls Leila. She was very close to the older brother, a civil engineer. In fact, most of the men in her family were engineers. “My grandfather is an engineer, my step father is an engineer, my brother is an engineer. I didn’t want to be an engineer.” Her mother was a nurse and her biological father owned a small business.

She was born and raised in the capital of a state in Northeast US, which she described as being mostly residential with a small downtown where the capitol buildings were located. In this city, most of the people work for the government, in medical services, or in small business. Leila initially lived in a more central and urban area of the city. She described the neighborhood based on the school district as a progressive and wealthy school district. When she was in the 6th grade, her parents divorced and she
moved to a more rural, peripheral area. In the new neighborhood, she found a different environment. She again described the perception of change through a student’s eyes: a successful student who came to a school that was below her abilities and expectations. At her new school, she saw herself as a student ahead of her peers and not growing intellectually anymore. She commented on her disappointment with being at the same level of other students in the 8th grade. She recognized this as an important period in making her who she is: a student who did not have a chance to develop her full potential. She saw it as an experience that limited her opportunities, wondering what would happen to her if she had stayed in the wealthier school. She wondered if maybe she would have chosen a career even in science.

When asked about a positive lesson learned from such a change in her life, no idea came to her mind immediately. Nevertheless, later, when reflecting about moving to college, she noted that having experienced moving also contributed to the development of her personality. She, contrary to her brother, was not concerned with coming to a new town. She was confident about making new friends, and building a new life. She also related her confidence and independent attitude to the divorce of her parents. When they divorced, she learned how to be far from her parents, and coming to college was not that scary to her. She had lived far from her father before. Thus, she knew how to do things on her own, and she did not need as much support from adults. However, the transition to college was not completely smooth, mainly because it involved making a choice. She was offered a scholarship in another institution and had originally decided to go there. A key factor in the decision process was a football game in the campus of the university she attends now. She came to visit and really liked the town. At the last minute, two days before applications were due, she applied and was accepted. Leila came, and she was happy about her decision one year later, but sometimes she wondered what life would be like if she had chosen otherwise.

Currently, Leila lives in a dorm with a high school friend. She recognized that having this friend eased the transition to college: “We knew we wouldn’t have any fights.”
In high school, Leila already “knew [she] wanted to be a teacher”. She attributes this goal to good experiences helping other people learn and an interest in seeing people grow and develop (like her little brother). However, “I didn’t know what I wanted to teach,” said Leila, and so she got involved in various activities for her to be able to better establish what exactly was “her niche” in the education and learning field. One important experience was when she was required to do 20 hours of community service in high school. Instead of doing “stuff like washing cars”, she wanted to do something that could be more meaningful. She volunteered to spend time with young children in an after school program. One of the lessons she learned from this experience was that she did not want to be an elementary teacher. In her view, kids are very dependent and you cannot establish a balanced and equal relationship with them. “It’s more like one baby sitting.” Later, she would have other experiences as educator, working as a tutor in Spanish and as a lab assistant in chemistry.

The teacher who really inspired Leila to pursue a career in education and to choose Spanish as a discipline was her high school Spanish teacher.

And I came to study Spanish because my high school teacher, my high school Spanish teacher is very, very cool. She made it fun. And I always liked Spanish. Like, I knew I wanted to be a teacher, but I didn't know what I wanted to teach and everyone tried to get me to go into elementary teaching and I was just like, no, I don't want to do elementary teaching. So, [during] my junior year in high school I helped tutor, like, for the Spanish department and that was a lot of fun. And so I was just like, I'll go for it, you know, why no?. And I want to go to Spain, so it's really good like to tell the parents, you know, like I have to go to Spain to study.

Maybe one could tell Leila’s story without ever mentioning science. In the first interview, Leila described her relationship with science as if she was relatively indifferent to it:

I don’t hate science, I don’t love science. It’s just always been the subject for me that I just do. You know what I mean? You just… Like, I had science in high school. I had biochemistry and physics. Umm…and I did well in the classes, like I understand science, I just, you know, didn’t want to pursue it any further.
Later, another picture emerged. Leila distanced herself from science: “I don’t drink in the same cup”. Distance, here, appears to be purposefully maintained, because “science brings a bad taste to my mouth”. However, this bad taste does not come from everything in science. Yes, Leila had an image of scientists as different (and special) people who do different things. Yet, she did respect scientific knowledge and scientists. What makes Leila “not drink in the same cup” were her experiences in learning science. It did not bother her to be told by doctors how to go about treating a disease; it did not bother her to have to do what scientists tell her to do (e.g. cloning). However, to have to engage in learning science was quite disturbing for her. She explicitly said that her problem was with “having to learn science.”

She described a series of negative experiences with learning science at school. In high school, she took Biology, Chemistry and Physics. In the Biology course, they were always reading from the textbook and memorizing information. In Chemistry, she had to participate in a series of laboratories in which she would just follow directions. At the college level, she was required to take three courses in science (one of them SCIED 410). In the semester in which the study was conducted, she had taken a lecture course in Astronomy.

Because like I had astronomy last semester and we were talking about like these black holes and stuff on the other end of the galaxy that like...you know, they were teaching us that this really exists. And I was kind of skeptical because I was just like, you’re telling me that it is true and that you know it exists out there, but at the same time, there’s so many different theories as to what... Like, I don’t really know which one. Like back then, I didn’t know which one to accept because there’s a lot of different theories and, you know, like a Penn State professor is telling me this, but then, you know, like there’s other things out there.

Usually, she would say that learning science involved following very specific steps and using a certain language, with little room for originality. In part, she attributed the sameness to the very nature of science.
I think in science class, and I come to sci. ed. four times, I think that way. When I'm in any science class for that matter, I think that way. Like last semester, astronomy, you know because we've learned the scientific method since you've been in like eighth grade or whatever. You know it. And it is...like I do know it. It's something that's in me. But when I'm out, just...when I'm not in science and I'm not in anything related to science, like everything... Oh, I just...I don't think that I think scientifically.

And,

I'm not a science person and like...and I think that has played a huge factor in this class [SCIED 410] for me because it's hard for me to look at things from a scientific standpoint. But I am learning how to do that through organization of the claim and evidence. So when I'm in this class, I'm focused on trying to think about it from a scientific standpoint. When I'm outside of the class, I just don't.

She perceived these same elements in SCIED 410. She expressed concern with having to follow very specific procedures, having to use a particular language, having to present findings in a particular way, and so on. That made the course tedious in the sense that she did not have a choice in what to do, it made all students do the same types of things.

Interestingly, when talking, she did not associate science to experiences outside school. As she reflected back about her experiences in the specific subject matter addressed in the course, she emphasized that she never wondered about nature before.

The truth is, I guess I never thought of it. Like growing up, I never... like they were talking about how the kids were asked certain questions and like they would give their answers and there would be misconceptions and whatnot. But like growing up, I really just didn't think of it. You know. Like... and again that's the truth. Like no one... I don't think I can remember anyone ever asking me like why can we see in a dark room. You know?

and,

My prior understanding [about evolution] was... See, this is terrible, I really didn't... like I had a prior understanding, but it was just more like, like these things happen. I never really questioned why they happen.
2.2 Conrad: I like the way scientific thinking is structured

Conrad was a 22-year-old student majoring in Secondary Science with focus on Chemistry. I perceived him as an introspective – and sometimes apparently introverted – young man. He is very reflective and dedicated to his work as student. During class, he would be concentrated in making progress with his investigations and during interviews, he would be willing to discuss in depth issues related to his own learning of science. He would spend hours in interviews with the researcher, and, once, he even set up an extra interview to further discuss with another instructor and I issues that emerged during one of the interviews. This gives a sense of the level of Conrad’s involvement in the research, as well as his constant curiosity about science.

Conrad was born in a town close to a big city, and moved to a very small and rural city farther from this big city when he was in the 3rd grade. The move was not described as particularly remarkable “I can hardly remember how it was before”. He remembered that before, his family lived in a townhouse in a neighborhood with multiple townhouses. Then, they moved to a much bigger house (4 rooms, a pool, a pond) in a development area. This house was close to a stream and to woods, where he used to play. One negative aspect of moving was that he had many friend in his original home town and for a while he had few friends in the new place. Fortunately, a very close friend moved to the same town, about the same time. In fact, Conrad’s family moved because this friend was moving and the two families saw that as a good opportunity.

Conrad was the oldest child of the family, having two sisters: one two years younger than him, at the time the study was conducted, attending a small private university; the other still in high school. He also had much younger brother (2 years old). His father did not have a college degree, and worked in a pharmaceutical company with waste management for about 20 years. His mother was a nurse. She got her degree relatively recently (a few years before) after taking some courses. He described himself as close to his family (“my father says that your family is everything you have.”) Indeed, a crucial experience in Conrad’s life involved his family: the birth of his young brother. Initially, the fact that they would have a new baby did not affect him much. “I guess I
was the typical self-centered teenager.” However, he assumed an important role in raising that child. He did not define himself as the primary caretaker, but when his mother had to work, he would be responsible for the child. This experience had a significant impact on his life. He became much more mature, realizing that he had a responsibility to be a role model. He also talked about how dependable a little child is on you, saying “you even have to remind them to eat!” Interestingly, he describes himself as someone who is “reliable”. Moreover, this is an important aspect in establishing relationships with others: he also looks for meaningful, reliable relationships. One example he gave was his long-lasting relationship with his girlfriend (an elementary education major). “We’ve been together since we graduated from high school.” Such a relationship involved a great deal of commitment from his part, like deciding to stay in the campus close to his home when entering college.

For Conrad, being an educated person is fundamental. “In my family it’s taken for granted that you gonna go to college. I think my parents wouldn’t accept that.” His experiences in working in “non-skilled jobs” confirmed the value of getting a college degree. In his conversations with these working-class people, they told him that he should get a degree; otherwise, he would work like them for their whole life and would not get anywhere. Moreover, he told me, he did not learn anything from doing this kind of work. The only lesson that he took from this kind of experience was to study to get a better job in the future.

Interestingly, he said he could not recall any remarkable experiences as student or think about particular teachers before college. He did not know how to describe his high-school well. For him, it was just an ordinary school, like any other: “What can I say about it?” He described his teachers as belonging to two categories: in middle school they had old teachers and in high school young teachers. He liked better the young teachers in high school because they were closer to students. However, some apparent conflicts emerged from the closer relationship with these teachers: being friends implied in expecting them to make-up for you. And that did not always happen.
High school involved not only a change in the kind of teachers, but also in establishing relationships that were more meaningful with other students. School friends became more than just colleagues at school – they would go to each others’ houses and do things together, developing a more personal relationship.

As a student, he described himself as someone who always attended AP classes in science and someone who was seen as the “good boy” by the teachers. Although he would say that he wasn’t exactly that good. His grades were high, though: “I never got a C” and are still high, “I have a GPA of 3.8.” The “stigma of good student” affected him considerably. First, in the family environment: “I didn’t want to get home and have to hear my parents questioning me [if I got a bad grade]”. Secondly, he was “really becoming too concerned with grades.” He sees that influencing his attitude as a learner: “I learned how to get an A without knowing as much as I should”, and, sometimes, learning became of secondary importance in a course.

At the end of high school, Conrad was not sure about what career he wanted to pursue, but going to college was indisputable. Thus, he entered college in graduate studies without choosing a major. After two years, he was required to make a decision. His interests in psychology led him to choose to major in health sciences. However, as soon as he made this decision, he started to think that chiropractics could be a good fit for him, particularly because he wanted to have his own business. Without changing majors, Conrad started to take courses that he would need for chiropractics, with particular emphasis on science and mathematics courses. Eventually, he would have to officially change his major. Before that time came, he had the chance to spend a day with an experienced chiropractic. He realized that chiropractics was not for him. You would have to lead by example and have a healthy life style, and he would not be able to do so. He did not want to take 27 credits and to spend all that money on something about which was not sure. He needed to rethink what to do.

Conrad considered going into Mathematics but taking into consideration the courses he had already taken, he concluded that if he chose science it would be easier and less expensive. What he liked about science and, particularly, mathematics was the
structured way of thinking involved in these disciplines. “Yeah, science has always been my thing and I guess chemistry...” For him, chemistry was closer to mathematics than other science disciplines and it fitted well with the courses he had taken so far. Furthermore, teaching seemed a good option. “I never realized it, and my Mom told me a while ago, that I’ve always like helped my friends through their classes and stuff. So I guess it was a natural connection.” Moreover, teaching would provide him a flexible schedule with summers off, “although I would have to give up the idea of having my own business.”

It was hard for Conrad to remember experiences on learning science before college. Experiences in high school were considerably negative. His Earth Science teacher is the one that came to his mind. This teacher used to hit a hammer on students’ desk to call their attention to what he was saying. Conrad did not like him because he was more concerned with students listening to him than with their learning from his class. However, a series of positive memories came from college experiences in a branch campus of the University that he attended for two years before coming to the main campus. There, he took courses in small classes (5-10 students) and had professors that were role models to him. Two science courses were particularly remarkable: Organic Chemistry and Biochemistry. In the Organic Chemistry course, he learned about ideas and principles instead of facts. The professor, instead of asking them to memorize the structures of molecules, taught them about mechanisms of interactions, and they would have to deduce and make inferences about these structures based on their knowledge. In the Biochemistry course, he had a chance to have open-ended experiences in learning science.

Because I had a Biochemistry class last semester that only had five people in it and it was... I thought it was very good. I mean obviously you're never gonna have five people in a class but just the way the teacher did it, he talked about the things that… Nothing was presented like concrete, it was this is what evidence has shown, it's probably the right way

1 He qualified this experience as “open-ended” in another interview.
to go because I guess biochemistry is one of the fields, the new fields, that they don't have concrete like definite answers for a lot of things and so you had to do a lot of… that the tests were a lot of, they give you what the situation is and you try and come up with your own answer to why that happened and if your answer made sense then you got it right. There wasn't a right or wrong answer. (...) if it, I guess, obeyed the laws of chemistry and biochemistry, if you used principles that are definitely proven, like polarity and enzymes and stuff like that, things that are actually proven to try and explain something that hasn't been explained. Does that make sense? (...) Yeah, we did a lot of like reading papers that… like new papers that just came out that are testing things. Like one of the things we looked at was there are some people that don't get AIDS, even though they've been exposed to it a lot of times and the paper went through and explained what they thought it was, what the evidence was. And then what we had to do is one of the groups… we split into two groups and one of the groups had to present the paper to the rest of the class and try and come up with ideas of how you could use this evidence and what you would do in the next experiment. (...). So, it was pretty enlightening, I guess.

Based on these experiences (bad and good), Conrad defined good science learning by saying that “Learning should be a discussion not a speech.”

SCIED 410 is grouped with positive experiences in learning science, particularly when he looks back to it – not as much when he was taking the course. At first, he thought, “Why do I have to take this course to become a chemistry teacher?”. Furthermore, he regretted the fact that there was not any module in the course on Chemistry. Later, he began to enjoy the course, mainly because he got to learn new concepts in science. He said he never felt uncomfortable in the course and that we instructors treated him as equals, and he appreciated that.

2.3 Caroline

Caroline was a 20-year-old Elementary Education major. In my interactions with Caroline, I perceived her as someone who could be very talkative and at the same time, very focused. In class, she would rarely take the initiative to interact with me as an instructor. In my perception, she liked to work independently. During the interviews,
she would give relatively detailed accounts of her experiences, but she liked to talk especially about her personal life and history (e.g., family, past experiences).

She grew up in a middle-class family, feeling privileged for not coming from a “broken home”. His father owned his own business and her mother was a business teacher who inspired her to pursue an education career. She had a slightly older brother, who was attending another university, majoring in telecommunications and minoring in theater. She described herself as being very close to her family. Because of this, coming to college was a relatively troubling experience.

Yeah. I was pretty homesick. It’s not that I hated it, but I was considering going back home for a year. But now I like it a lot. Now it’s like, besides missing my family, I don’t want to go home. I have fun here. You know. And it’s nice being independent. So. I’m glad I came here though. I was gonna stay at home and go to [another campus], which is like ten minutes away from my house. But I’m glad I didn’t because I think I needed to move out of my comfort zone. You know, I was really comfortable where I was at, but you know I wanted to, you know, try something different.

Before coming to the university, Caroline came from a relatively big city, where she attended school in the same township.

I was pretty stationary in my education. Like, I went…well, I went through like K through five elementary school and then…in Blue Moon Township, where I live. And I went, you know, right next door to the middle school that had sixth to eighth grade. Caroline described the district as “your typical like predominately like white, middle-class high school”. She attended to relatively big schools:

… it’s a fairly large school district. I had…there were a lot of elementary schools in the same district. There were three middle schools and there was only one high school. And I graduated with, like, a class of 600 in my high school. So it’s a very, very big school. … Like, they had a huge school for ninth and tenth grade and a huge school for eleventh and twelfth and it was still crowded.

2 This is a pseudonym.
In fact, the district was a quite wealthy district.

*It was probably one of the wealthiest school districts in terms that, you know, our buildings and our resources*, you know, we had a lot of computers, we had a lot of, you know, a lot of, you know, really good sport facilities and stuff like that. And, you know, we had a planetarium in our high school and we had like all these things, you know, that I was really fortunate to go to a school like that, I think.” (my emphasis)

Considering both “benefits and disadvantages to that”, she believed she got a good education there.

I got, you know, a really good education in the school district I was in … And I can see that because in my first year of college so far, I’ve used so much of the information that I learned in high school. And, you know, I thought, you know, okay, you know, high school definitely prepared me for college, but I didn’t think I was gonna really actually be able to like apply some of the stuff I’ve learned. But, you know, I know, you know for example, I took psych II last semester and I see like it made so much sense to me because of the psychology class I took my senior year….I think there were more options for different classes you could take. I mean I had like some of the best classes. Like, I took a child development class. It was just so awesome. My teacher was great. We wrote, like, our own children’s books. We, actually, every other day we actually went out, like one of the girls in our group, like, we were separated into groups, would drive out to elementary schools and we would actually make lesson plans and teach the kids. And that was, like, the best experience. … And our teacher was great because she wasn’t the traditional lecture method teacher, she was the exact opposite and she wanted us to get out of the classroom as soon as possible and actually go out into the other classrooms and use what we know. And that was, like…that was a really great class. And so I had a lot of good background in my high school.

These experiences in the child development class were particularly decisive in her choice of a career. Referring to this course she said,

That’s what really made me decide I wanted to be an elementary teacher because I just loved it, like actually working with the kids. And I mean it was such a good experience …
As student, Caroline defined her self as a high achiever: “I can’t get a B, I can’t get a B.” She would be always in honor classes. An exception was in junior year in high school, when she attended a regular class in chemistry. This was extremely uncomfortable for her. Nobody wanted to learn, nobody had respect for the teacher. It was terrible. People would sit close to her to cheat in the exams. Moreover,

You know, it was just like chemistry, ugh, you know, this chemical does this chemical and it has this atomic number. To me, it meant nothing to me. I was just like, okay, you know I have to do it.

Before that, she had Biology.

Oh, biology was like by far the most horrible class I’ve ever had. I had a teacher…I was in an honors biology class, and our book was about that thick and tiny little writing and it was straight lecture. Straight lecture. I mean every now and then we did a lab. But she would hand us a packet and we would just copy right from the overhead. And I didn’t learn. I mean every test I took, I just memorized. I couldn’t spill out anything more than information. I couldn’t explain anything. It made no sense to me. And I didn’t look forward to that class.

However, in the past she also had good experiences in science. As early as in the 5th grade:

…I had this awesome, awesome science teacher and she was just great. And like, she did this program called Young Astronauts” and it was like after school, like outside of school. She would do different, you know, hands on projects. Like one time we went to like, you know, an airport like out in the country and they were talking about, you know, like airplanes and stuff like that. We actually like made our own little rocket models and stuff like that and set them off in the back of the school. And like she was just real, real hands on, always having people come in, doing different experiments. You know, we were like…you know, it was animals all over that classroom, you know, hatching like little chicks and stuff like that. It was fun. I mean like, you know, I always remember like her and stuff like that and, you know, how like we couldn’t wait to go to her class. And, you know, I think I'm aiming to be that kind of a teacher because I think that, you know, everyone loved science. Science was like the greatest thing in elementary school. It was
like reading, ugh, math, ugh, science, yea. So, yeah. So, I had a good experience with that…

Then in ninth grade, she had an Earth Science class:

I’ll never forget my ninth grade science class…it was earth science and it was like a mixture of like astronomy and then there was like meteorology and there was like rocks. So we did like, you know, rock projects and we did national park projects. You know, some people could just fall asleep talking about rocks and I was like so excited about it. I don’t know, it’s just an interest that I have. And you know, I just like think… I guess like… I like earth science because I think like the earth is just like so incredible, like the structures you see, like the geography, it’s just like amazing to me. You know, I really am intrigued by it. And I took Earth II last semester and I mean I loved that class so much. And I did really well in it too because, you know, I think those concepts are easier to grasp for me… like for astronomy, like we got to go in a planetarium and that was like so cool, you know, it’s like wow. You know, he would like show us the stars and stuff like that and we would, you know, have classes in there. And then umm…we were, you know, like I said, we did a rock project and it wasn’t boring because we had to find…we were required to find certain types of rocks, but there was a contest of like who had the most creative project. Stuff like that. So he made it fun. And then, also, with our national park projects, like I like doing that. *I like independent work and stuff like that.* That was a long presentation also that had to be like a half hour to forty-five minutes long. And you did that independently and stuff like that. Everyone got assigned a national park and you had to like, you know, explain the geography and different stuff like that, you know, important facts, how it was formed and stuff like that. And then he also showed like a lot of like slides and stuff in class. (my emphasis)

Finally, in college, she took another Earth Science class:

I really liked my professor and he was interesting and he knew a lot. Like the main topic was global warming actually. Like the first half of the class was, you know, basics about what we would need in order to understand global warming. And then we talked about basically what the earth is gonna look like in the future and like what’s gonna happen because of global warming and stuff like that. So we didn’t really do…there wasn’t really much, you know, class interaction and we didn’t have to do any projects or anything like
that. It was a fairly large class. But umm…you know, just like…I didn’t really get bored, just because I'm interested in stuff like that.

From my reading of Caroline experiences, a pattern appears to emerge. Her positive experiences involved being active and creative, sometimes with hands-on activities, some times with projects and presentations. These experiences also involved a contact with concrete aspects of life outside school, going to a field trip outside school, seeing pictures, bringing animals to the classroom, or role playing to simulating a real life problem situation. Topics related to her everyday life seem to be particularly motivating to Caroline. On the other hand, her negative experiences in science involved abstract topics. Moreover, these experiences are connected to a way of learning that involved being lectured, memorizing information, copying and following directions.

2.4  Matt: About things and people

Matt was a 19-year-old freshman majoring in Secondary Teaching Social Studies. He was brought up in a Christian house, the oldest of the family, with two sisters (16 and 18 years old). His father works in a factory and his mother is a nurse. He was born in a small town where everybody knew everybody, where “people had eyes and ears”. Although living in a small town meant not having the freedom of anonymity, it also meant that he was among friends, almost like among family. People he could trust, people he knew, people he could share everything.

Religion has been always a part of his life. He had to go to church on Sundays to have lessons on catechism. Looking back, Matt said that he did not really care about religion. He would go to catechism lessons and it would not have anything to do with his life. The teachers would ask him what the role of God was in their lives, which at the time, he did not know. It was only when he moved to college that God and religion assumed a clear meaning in his life. Being alone and far from home made him reflect about many things. He was almost homesick. Not that he missed his mother; he missed his best friends. He missed being around people whom he knew and who knew him. He started to judge people. Then the meaning of God became clearer. This appears to be a
moment of revelation of the meaning of religion in his life; however, he can look into the past and see how religion was present. In high school, for instance, some questions and issues surfaced. In an English class, he learned about the *isms*, that is, perspectives such as existentialism that at their core questioned and critiqued religion. As a result, he struggled with some profound questions about his faith. He even questioned the value of this faith. However, at that point, he engaged in intense dialogue with friends and meditated about these issues, a process that had a closure only after moving to college. Interestingly, he did not see much conflict between science and religion because he did not care much for science. Matt did question religion, but it was due to philosophy, not through science.

Matt also talked about his hobbies. He really liked to play soccer. His father wanted him to play minor league baseball, but he wanted to play soccer. He liked soccer because he had to be always thinking. In (American) football, you always stop for 40 seconds. The player may say 40 seconds goes fast but it is not the same. In soccer, there is no stopping. Another thing that he did a lot is to listen to music, paying attention to the lyrics. Listening to the music awakened powerful feelings in Matt. For him, books and poems, when you read, may make you feel emotions, but when you combine that with music, it creates much stronger emotions.

His interest is really history. He describes what he likes about history:

I just like…I don’t even know. I like learning about how it used to be and how it is now and just how like how our social patterns evolved. It just amazes me... And how like one event can completely change like the mindset of an entire like...of the entire world for like the next centuries to come and like things like that. I just...that’s really interesting.... Umm...just like...okay, one thing might be maybe like slavery in this country and things like that. How it used to be that they were like barbaric and then it was just, oh, they’re inferior. And then eventually, you know, move to, well it shouldn’t be okay to have them as slaves but they’re still inferior. And then...you know, just how it evolved up through today and how maybe it’s gonna be in the future. Things like that I think is really interesting to me. How like one event like, I don’t know, maybe like the civil war, it like completely changed like the country for years to come.
In other instances, I identified in him the same notion that history is made of key events that completely changed the world. Usually, in his examples he mentioned powerful individuals (such as the president of the US) who made the decisions that defined the fate of the humanity. The example of how the world would be different if the president had not decided to bomb Japan with atomic weapons, further illustrates this idea. For Matt, these understandings go against the concept that history is merely a bunch of facts. To see history as a bunch of facts would involve only on giving dates and facts.

The way Matt related to science was very different from how he perceived history.

Science is not something that I really care about, like history. I cannot stomach more than one semester. I don’t have interest in science beyond the superficial, the general education. If you go further, I don’t like it.

Science is about things not people. For Matt, chemistry is the epiphany of what science is: you mix things, you follow directions, and you have to find the right answer, even if you got the wrong results. In science, there is no room for different opinions. There is always one right answer. All the processes of science are about getting to a right answer. Even if you do not know what that right answer is yet, you look for it, like in global warming. History is also based on evidence (or facts) like science, but you can come up with different perspectives, unlike in science. Moreover, in history, there is space for one’s own perspective to play a role, not in science. He would never choose a career in science because he really wanted to make a difference, to affect people and see it, which is one of the reasons he chose to be a teacher.

Growing up in a working-class family, he saw education as the best path to a good future. His father had worked all his life with little economic security. Thus, to do well at school and come to college were particularly significant to him. In his case, academic success meant social ascendance. However, his standards were not as high as Caroline’s. To him, getting good grades means not getting Cs.
In his education, his English high-school teacher was particularly influential in his life. From her he learned that he did not have to feel that he had to fit in with everyone else. Moreover, he realized that one has to have his/her own opinions. Yes, you have to get good grades, but this is just because it can affect your future.

A biology teacher also was a good influence, seen as someone who would treat students as equals.

He was a really easy guy to get to know. He was real student-oriented and like kind of like one of those teachers like he’s your best-friend-type guy. So he related really well to the students and for that he had a good learning environment I think because of that. And he was able to get his material and his point across in class very easily. This was like four years ago, so I'm struggling to remember everything about him. In that sense, like he was just…he was somebody that as going into the teaching profession, like he’s the one that I would…I try to…I look up to and I would want to model his style.

I thought my teacher did a really good job of it [teaching evolution]. I was telling somebody yesterday, I don’t remember who it was, but... I don’t know, I thought he started it off real well with like refuting, well, not refuting creationism, but just showing that evolution is not... like it’s not like infringing upon your religious beliefs in any way. This is, you know, like he said, I’m not here to change your mind, I’m not trying to tell you this is correct, you know, you don’t have to believe it, but this is just scientific fact and this is what is widely becoming known as the truth. And umm... I thought he did a really good job because I just... well, if I was…I thought I was pretty close in a lot of these things. So if I can remember it after five years that much, I think he did a pretty good job. (...) I think it was like a lecture, like he did a... He would lecture on something and then I think he usually went back and did some kind of experiment or lab that would prove it.

"After ninth grade biology, it was downhill". He did not remember any other good experiences in science classes. He had a “good anatomy teacher”. She was tough, but he was not interested in anatomy. His physics teacher, on the contrary, was a “poor teacher”:

He was very disjointed from the class. Like he would give us a lab to do and send us off to our computers and he'd play computer games. And umm... he would teach like two days
out of the unit, like actually like just teach. And the rest of it was just like, well, you know, read the book and try to figure out the lab on your own. It was the closest thing to inquiry-based education that we had. But if he was going for inquiry, it was really ineffective because it just left us like it just left the class in like anarchy, like trying to just get answers any way you could. Like if you had to like con the answer out of him, like just talk it out of him or something and then give it to everybody else in the classroom. It was just like get it done however you can because no one had an idea of how to do it. And it was just really frustrating.

3 Learning about People, Learning about the World

One could argue that the detailed information about participants presented in this chapter was not pertinent to the study. Indeed, as we saw earlier, this information has little importance in analyzing their performance from their instructors’ point of view, or to measure their learning based on how much information and strategies they acquired. At most, one could make inferences about the causes for difficulties on performing appropriately.

However, from my perspective, as I examined in depth who these people participating in my study were, I constructed an indispensable knowledge. Leila and Matt were not simply college students who were not majoring in science, who hated science and had little background in the field. Caroline was not simply the typical elementary teacher who loved children and did not want to engage in science. And Conrad, was not simply a science major who was born wanting to be a scientist and knew a lot about science (or too little about science). The participants were not only college students and prospective teachers, but also women and men, sons and daughters, brothers and sisters, with motivations, religious beliefs, emotions, conflicts, and with past and future. They became people, complex, multifaceted and incoherent as anyone. More important, as they gained life, they became agents in the process of learning through argumentation.
As I leaned more about who the participants were, I could better interpret the meanings they constructed of their experiences. Afterwards, these experiences were not only situated in a physical/objective space, but also in a dynamic context of interactions between people and things. Thus, considering the perspective and the focus of this study, I believe that, without learning about participants, it would have been impossible to learn about how these people experienced argumentation and argument construction in science. In the next chapter, I turn to my interpretation of these experiences, which, now can be situated in the context of people too.
Chapter 7
Interpretation of Data

1 Introduction

In this chapter, I present the categories that I developed in response to the research questions based on my analysis of data. As I define these concepts, establishing their limits and relationships, the reader should keep in mind that this study is about situated argumentation. As I generated these concepts, I considered the context in which the argumentation took place as key to shaping the participants’ experiences with argumentation. In particular, the notion of situateness refers to the ‘immediate’ context of the SCIED 410 course (e.g., tasks, subject matter, interaction with instructors). I encourage the reader to be attentive to this aspect of the context as she/he comes into contact with the concepts. The reader needs to be attentive to the fact that concepts originated in part from comparisons that the participants and I made within this major context (e.g., between two modules). At many points in the chapter, I will revisit this notion of context and make explicit relationships, but the reader would benefit from keeping that context in mind all along.

Moreover, as I constructed a response to the research questions, the process of analysis involved raising questions as much as providing an interpretative account of these experiences. Consequently, the presentation of categories is punctuated with questions that are not always immediately addressed. Through these questions I want to call attention to contradictions and patterns that I recognize in the data. Frequently I will build on these questions later in the chapter as new ideas/concepts are discussed and new relationships are built.
2 Argument building as legitimization and argument building as means

In addressing the question ‘How do prospective teachers experience the situated process of argument construction in science education?’, I focused on the PTs’ perceptions of the very experience of argument construction in which they engaged. My interpretation lead to the notion that the process of argument construction was experienced as involving two major processes: argument building as legitimization, the most prevalent one, and, argument building as means.

To construct arguments in the context of this particular science course, prospective teachers engaged in a process of using the structure that was provided by the instructors. Using such structure did not imply embracing the same meanings and processes envisioned by educators. As learners constructed and attached their own meanings to the structure, they developed their own rationale and actions. Thus, what initially was an abstract and given argument gained new life: complex processes started to take place in the situated argumentation, processes not necessarily anticipated by those who designed the structure. Situated argument construction for prospective teachers involved two major processes: argument building as legitimization or the use of the argument structure to make one’s argument valid and acceptable, and argument building as means or the use of argument in facilitating or inhibiting the process of the development of explanations to better understand a problem. In the first case, the focus is on gaining ‘authority’, in the latter the focus is on gaining ‘ability’ to construct explanations. These processes were not mutually exclusive, participants experienced them in the same investigation at different stages and in different situations. Nevertheless, argumentation as legitimization prevailed. It was the most powerful process driving PTs experiences, and they consistently relied on this type of process to proceed with argument construction.
2.1 Argument construction as Legitimizing

“like one time like one graph we chose to make was like of the beaks versus like living and
dead birds and we were like, oh, look at this, you know, because it was all separated. And
we just came up with that hypothesis. And so that was like our initial hypothesis. And then
it was kind of like we didn't explore any other hypotheses and so we just... we just filled in
the information. Like, we went back and made it true. But it actually was true, so it was
kind of like. Like it could have been bad if it wasn't true. You know? But it kind of worked
out okay.”  (my emphasis)

Leila’s (pseudonym) account of how they constructed their argument in the
Evolution Module represents an extreme illustration of what I interpreted legitimizing
arguments to be: to make something true. Although legitimizing is rarely expressed in
this extreme form, the issues underlying this type of experience were present throughout
the course. How can I make my explanations acceptable? What should be the key
characteristics in my argument for people to see it as a valid idea? What makes
explanations worthwhile? Note that to make it true (or to make it acceptable) does not
always imply that it is true (or that it is an explanation that helps me to learn about the
natural world). These are seen as two distinct processes, and notably, legitimizing the
argument came first. The major concern, at that stage, was to make the explanation
acceptable, not exactly to see if that explanation had the potential to account for the
various aspects of the problem posed. Consequently, in this context, the problem
acquires a different function. The learner is not trying to understand the problem and to
solve the problem; he/she is basically looking for an acceptable solution.

Considering this specific role, what do I do to my explanation so it is appropriate
for legitimization? Three attributes were identified as being important for PTs in SCIEd
410: the argument is concrete, the argument sends a clear message, and the argument is
articulated in an appropriate manner. Notably, these aspects of legitimization are
recognized by PTs as relating to a context for legitimization.
2.1.1 Concreteness

This attribute represents the participants’ notion that to have something tangible and concrete is essential to make one’s argument valid. In fact, in many instances, it is expressed that you cannot even say anything if you don’t have tangible evidence to say it. Caroline, for instance talked about her rationale for not including alternative explanations in the Climate Change module:

C: I think we did think, you know, discuss like alternative explanations, but if we really didn't have much to back it up, we didn't really like, you know, waste our time, you know, creating any kind of explanation page for it...

we kind of went with the like solution or whatever, the answer that we had the most to back up with because we just thought that would be better for our argument rather than, you know, having no claim. But even if we... I mean most of it, we both basically agreed on the same ideas. But if even if we did, you know, like have like, you know, conflicting...
or we went more towards an explanation that had like weaker evidence, I think we'd stick with the one with stronger, you know, just for the general purpose that, you know, the more evidence you have, the better your argument is gonna be.

Caroline – Post-Global Climate Change Module Interview

I interpreted this statement as meaning that you better not say anything than say something without having evidence to support it. If you don’t have such a concrete back up, you may be “making things up”:

Like we never made anything up. I mean we always backed... like we always had information to back up a claim, but it would just... it took awhile to get that information.

Leila – Post-Evolution Module Interview

Moreover, one may be too emotional (even if you do it in contexts other than the classroom):

Well, I have a lot of different opinions on that, but while they were… when they were like shouting that and screaming that and when they proposed it to the administration, like it was just almost like they were stating what they wanted and they didn't really have any
reason to back it up or they didn't list any advantages or causes. You know, like it just seemed more like an emotional based claim than like anything.

Leila – Post-Global Climate Change Module Interview
(talking about the a Anti-Hate Rally in campus that she supported)

As one relies on this ‘concrete information’ or ‘concrete reasoning’, the best she/he can get is to have physical evidence to show that her/his ideas are valid. In other words, the ‘highest status’ of concreteness is to have the material/physical evidence to support your explanation. There is a clear difference between having and not having this type of evidence: I see it or I don’t see it. The value of being concrete is not diminished even in the face of authority (e.g., being a professor), since authority can not always be equated in power to the really concrete. Moreover, the value of being concrete does not necessarily emerge in the context of the course, but can be reaffirmed there:

(... ) there's some things in science where like you only have the explanation, you don't really have any physical evidence. And so I think that's very important. (... ) Because like I had astronomy last semester and we were talking about like these black holes and stuff on the other end of the galaxy that like... you know, they were teaching us that this really exists. And I was kind of skeptical because I was just like, you're telling me that it is true and that you know it exists out there, but at the same time, there's so many different theories as to what. Like, I don't really know which one. Like back then, I didn't know which one to accept because there's a lot of different theories and, you know, like a Penn State professor is telling me this, but then, you know, like there's other things out there. So. Like for me, like physical evidence is important I guess too.

I: So you kind of asked them, why should I believe in you?
L: Yeah, because like... like he was... like they had a very strong argument. You know. Like it was very well persuasive and like we... like this is what we should believe. But when it came like down to it, I was very skeptical.

I: So you think sometimes scientists can convince you, but don't show-
L: Well, it's not that they try. But I think in some... like astronomy, it's very hard to find you know, you can’t fly out to the galaxy, you know, to black holes and whatnot. So all they have to go on is their theories. You know.

I: And their theories are supported by what? Like where do theories.
L: Like with evidence. You know, like I need.
I: Yeah. Do they have any kind of evidence? (...)
L: Well, like they had... they had evidence but it wasn't conclusive enough. You know, like they were like, we know that black holes are this and so therefore, you know, a major, you know, explosion in space would cause this to happen. But at the same time I'm like, well, it's never really happened, how do you... like you can’t just... like it was hard for me to just go on word alone. Like I wanted to see it. You know.
I: In this case, [In the Evolution module]... like when you...
L: And in this case, we could see it. You know. So that was good. Because we could make the graphs and we could see it right away. So it was like providing evidence real quick. So I liked that. (my emphasis)

Leila – Post-Evolution Module Interview

These differences between seeing and not seeing acquire deeper meanings in the context of science argumentation and learning in SCIED 410: physical evidence means certitude whereas a lack of physical evidence is questionable and uncertain.

C: I think a lot of the stuff about the finch module was up in the air. Like it was hard to say, you know, is this right or is this right or, you know, who's more right and you know what I mean, who's closer to the right answer. Because, you know, we really didn't know. It was kind of like we were all, you know, formulating our arguments or whatever. But I think in light there's more, you know, definite, you know, answers. I think there's more like less lee way for. I mean I definitely think there's, you know, room for error, you know, no matter what you're doing, but I think there's less room for error because there's, you know, definite things you see, you know, definite properties that are there. Whereas, there was less of that in the finch module. It was more like you were just kind of going off on your own ideas. Whereas, you know, a lot of us. you know, I only saw two of the presentations, but from like talking to other classmates, a lot of people had, you know, we all knew as a class together the same exact, you know, information. We did the same exact experiments. You know, pretty much as a class we came together with the same conclusion. So it's like we started off almost with very similar claims, very similar arguments, but we just applied it in different ways. Whereas, in the finch module, we were all doing the same exact thing, but there were many different versions because there was.
I think there was, you know, more open ended like questions kind of. If that makes sense.

Caroline – Post-Light Module Interview

M: I thought Joe's [Light Module] was black and white. Like there was no other way you could see it. It was like a fact. So that's the difference.
I: The light. Did you feel more confident when you made your claim?
M: I felt more confident in the properties I was discussing. Yeah, and more confident in the claims I think because umm like light is reflected, you know there's no other way you can interpret that. With this, I think it's just because like even there's so many experiments that like it could, that like there could be like an outside variable affecting it and there's just no conclusive way to put it. Like you can make a hard case against it but you're not gonna prove it one hundred percent. Where with the light, like light is always going to reflect at that angle, it's like it's a property, it's a fact. Like we were discussing yesterday. Like your theories and your facts.

Matt – Post-Light Module Interview

In my perception, as PTs moved from constructing explanations based on indirect evidence (e.g., changes in patterns of traits frequency in a population) to constructing explanations based on experimental evidence, they felt much more confident about the validity of their argument. If you see something happening, there is little (or nothing) to be said, to be explained and to be discussed. It is as if ‘reality’ has materialized in front of your eyes.

2.1.2 A clear message

In the two last quotes presented above, Matt and Caroline talked about how having something concrete made their argument stronger. In both cases, underlying the notion of having something concrete was the idea that the concrete make things clear and unambiguous. What else could one see here? This power derived from concreteness, but also originating through other processes, is represented in the concept of a clear message. It rests in the notion that in a good argument there is no place for uncertainties and
ambiguities; what should be presented is a clear message showing how a particular explanation is the right one.

Well... if you're trying to build an argument, I don't think that evidence that I just discussed with heating the carbon dioxide, I don't think it refutes our claim or contradicts it. But it puts it into doubt. And with a topic like this, it's just kind of assumed, I think that you're gonna have doubt. And the goal when you're presenting an argument is to minimize the doubt as much as possible. And so I think we would omit that evidence because we don't want there to be doubt in the audiences’ part. And so that's what's gonna go into the justification is what evidence puts the... solidifies the argument best or will be most that will most benefit our argument to like kind of persuade, I guess you will, the argument to our audience. (my emphasis)

Matt – Post-Global Climate Change Module Interview

In part, to have a clear message is described as searching for obvious and conspicuous clues that will lead you to the right answer.

I mean when you look at the evidence, there was really no other answer that could be like. I don't know when you looked at things, you just kind of knew that it's not that, it's the beaks.

Matt – Post-Evolution Module Interview

Nevertheless, in my interpretation, there is predominantly an active process of suppressing conflict and ambiguity in the argument to make it reflect an apparent agreement. Sometimes eliminating conflict demands a lot of effort, like when Conrad decided to completely ignore some initial ideas that he had about light’s behavior. However, all of the conflict he experienced at the beginning of the unit (and that lasted until its very end) was not included in his argument. In other words, exploring or even describing conflict did not become part of his experience in constructing arguments.

I learned that it travels in waves and that like the speed of light is the wavelength times the frequency is basically just what I've dealt with in like two semesters now of physics. And now I came here and saw that it travels in straight lines. So I don't know what to believe. The only thing I can think, that I've come to the conclusion in my head is that it doesn't
necessarily travel in straight lines as much as it travels in such small wavelengths that our eyes can’t see that it's not straight lines. That doesn't make much sense to me. (... )

I: in this module when you saw the image in this screen [in the pinhole experiment], you said, oh my gosh, it travels in straight line, I have here big evidence that powerful evidence that it's traveling in a straight line. If there's something that you saw or you were told about.

C: That said it traveled in waves?

I: Yeah. The same way. Like.

C: Like this is when we did experiments in, I think it was Physics XXX.... I don't know which one, but when we shone light through a slit, we saw things like this. This single slit interference pattern, where we have a dark fringe here and lighter fringes all the way out. We also did things with double slits and you'd always see where as the light went through the different slits, as the wavelengths combined in different proportions, you'd see a different intensity of light. (... ) Like that's why I drew this one darker than the rest. That one would be darker. And I would of expected, when we did this pinhole camera, that the center circle would be really dark and then faint circles going out.

Conrad – Post-Light Module Interview

Despite this consciousness of deep conflict, no reference to this ambiguity and his struggle to deal with it was included in Conrad’s argument and he does not want to discuss it in class:

C: I didn't say anything in the class itself because I thought that would get everybody off track and mess everybody up. Whereas, it wasn't that important to me to like take the class in a different direction than it was going. I don't know.

I: Okay. No, I just think that was .I mean, excellent that you had this idea and I mean it's great when people have different experiences that kind of go against what they are seeing in the classroom and I was wondering if you kind of felt, okay, this is what they are presenting me, so I should ignore things that are from other [inaudible].

C: I don't know that I ignored it. I more.

I: You kind of decided not to bring it up.

C: Yeah. I avoided the conflict pretty much. Like I didn't want to open that can.

Conrad – Post-Light Module Interview
Interestingly, in addition to eliminating ambiguity in the form of contradictory evidence, there were other ways for one to be confident that a clear message was conveyed. One also can work on eliminating contradictory and multiple explanations. Caroline, for instance, talks about the importance of making sure that you have examined and discarded all the alternatives to have a really strong argument. Can one conceive a clearer message than that?

I felt much more confident about our Light Module presentation than I did about our finch module presentation. And I think it's because I was worried that in our finch module, we didn't cover all the areas that we should. And I noticed that a lot of people did cover other areas, you know, that we didn't, you know, and vice versa. You know, we might have covered things other people didn't. And so, you know, I was always. I think in the back of my mind, I was worried, you know, okay, you know we think this because of this but, you know, did we look into this deep enough, could we have found more here or more there? Whereas, in the Light Module, I think it was just so clear and so evident for us. Like, you know, for example in our telescope, it was so easy to explain it because we could see it. Like you could see the light hit the mirror and go straight down through the lens. I mean it was like right there in front of us and we were, you know, able to, you know, really work off of that and go into our argument feeling really confident about it because we feel like we've pretty much, you know, covered all the factors that were important and essential. Whereas, in the finch module, I think it was much easier to overlook little things like that. Like, I know we didn't really pay much attention to males versus females in the finch module presentation, whereas some people did like a whole section on it. You know. You know it's kind of like, you know, we didn't think it was important but, you know, another group was like, well, you know, how do you know and you know I'm like, okay, you know, I guess we could have looked into it more. I don't know if it would have made much of a difference, but then again, you know, that's another question that we, you know, didn't really have to write the answers to.

I: Well, but that point, you had a response to that.

C: Mm-hmm. Yeah. And we really didn't feel like it would have made a big difference. But, you know, it's just something, you know, like that, you know, I kind of thought of. And not just males versus females, but just in any part of it. You know, did we overlook something. Was there like, you know, a field note that could have helped us more or was
against us that would have been. You know, *I think there's much more room for error in the finch module than there was in the Light Module.*

Caroline – Post-Light Module Interview

2.1.3 Articulation

Finally, one of the attributes of a valid explanation that has not been discussed is articulation. Again, Conrad’s conflict experience in the Light Module is used to illustrate this aspect of articulation. Conrad was conscious of a conflict between two understandings that he held. He made a choice to not address that conflict in his argument, but why? First, to address a conflict per se, was seen as problematic from the perspective of those constructing arguments that needed to be legitimated. Moreover, Conrad explains that he chose not to address such a conflict because he could not describe, with the appropriate precision, the origin of his idea that light travels in waves:

I guess what I've told myself is that I don't remember the experiment right, that there's some kind of twist in that that I'm not remembering that would explain the difference. [i.e., to conciliate the wave ‘theory’ and the straight line ‘theory’]  

Conrad – Post-Light Module Interview

There must be some explanation for it, a *clear* explanation, I have to believe because I don't think there's that much variation between like visible and not visible lights and all that stuff. So, maybe the experiment is not how I remembered, the other one. I guess that's another reason I didn't bring it up. I wasn't absolutely sure enough to explain what I was talking about and ask why, how you compare the two, because I didn't know how to explain specifically what I was talking about. Like I'm having trouble explaining it to you. (my emphasis).

Conrad – Post-Light Module Interview

These quotes were interpreted to mean that if one cannot clearly explain some of the ideas they hold (and where they originated), these ideas tended to be ignored, and consequently, the underlying questions and issues were ignored. Within my perspective, this situation turned out to be a kind of a Catch 22, because the process of argument construction loses much of its transformative potential. It is not surprising that the most
ambiguous ideas were generated outside the organized context of the course, and these ideas were the most difficult to articulate. If for some idea to be expressed (and, in this case, became part of the arguments) it has a priori to be clear and well-articulated, it is unlikely that ideas that go against the most obvious or most clear explanation would be explored. The argument resulting from such a process tends to only reinforce the notion that only unambiguous and well-articulated ideas belong in an argument. Due to the process through which it was constructed, the arguments indeed contained relatively clear and well-articulated explanations. No one took the risk of dealing with more complex ideas and issues. Thus, we enter into a cycle in which the three attributes of legitimization (concreteness, clear idea, and articulation) reinforce each other.

2.1.4 Legitimization as sensitive to context

In some cases, the nature of legitimization (and concreteness, clear message and articulation in particular) is affected by the context in which it takes place. Of course, as I will discuss later, there are contexts that promote or hinder legitimization as described so far. However, when I refer to context affecting legitimization, the relationship is not necessarily the same. In fact, my interpretation indicates that the context can change the nature of legitimization. A single example illustrates how this category context for legitimization was defined. All the participants talked about the notion that you cannot say anything without having evidence as almost like a dogma or a universal law for argument construction. In fact, PTs consistently used evidence to support their ideas in the limited context of the course activities and assignments, coherently with their repeated statements that they would do the same in any context of argumentation (i.e., at school, in the dinner table). An exception occurred when Matt did not include pieces of evidence to support his ideas in response to one of the assignments (Figure 7.1). What happened in that new context is hard to determine, Matt speculated about his reasons, since he was unable to remember what took place at the time.

M: I was only considering, when I said that too, I was only considering that if you're gonna make a formal piece of writing that you kind of have to back it up or, you know, whether it's a formal speech or a formal paper. As I demonstrated very clearly, I think that claim is
very accurate that you don't feel you need the evidence when you're in an informal setting because I honestly didn't feel the need to because... like I... I don't know. Especially, when you're like in a classroom, like this is kind of like amongst your peers type of thing. Like I more than likely assume that like when I said the discussions about our atmosphere seemed logical, I assumed that you would know what the discussions in class were and that's stupid. But...

From: Danusa Munford (dxm320@psu.edu)
Sent: 2001-04-17
Subject: Reading 3: Global Warming on Trial Part 2
Message:
After reading the article and engaging in the activities in classroom, what is your position in relation to the question: "What is causing global temperature change?" Explain your reasoning.

From: Matt
Sent: 2001-04-19
Subject: Re: Reading 3: Global Warming on Trial Part 2
Message:
After finishing the second reading and further engaging in classroom discussions, I still have not been convinced of the cause of global warming. The article offers three different explanations for why the climate might be changing. These are sunspots, volcanic eruptions, and wind and ocean tides. However, each of these possibilities was deemed inconclusive at the end, leaving us with no further discoveries. On a separate [sic!] note, the discussions about our atmosphere in class did seem logical to me. As a result, I still maintain that the possibilities of global warming are not yet conclusive but that it only seems likely that adding gases to our atmosphere, like carbon dioxide, will cause some damage, whether it be now or in the distant future.

Figure 7.1: The question posed by the instructor in an electronic discussion in the Climate Change Module, and Matt’s response to the question.
What caught my attention in Matt’s comments? First, Matt made a distinction between formal and informal settings. In formal settings, for your argument to be considered valid, you have to follow certain ‘rules’, constructing your argument in a certain way. Some commonalities between legitimization as a set of rules, and the structure of an argument used in SCIED 410 surfaced in Matt’s explanation. Note that in this case, his explanation still focused on making his argument acceptable and valid. Although he was referring to more loosely established criteria, in my perception, he showed little concern with having an explanation that would help him to better understand the problem. Another interesting aspect in this participant’s comments was his reasoning for not providing evidence in informal settings. I inferred that, within his rationale, one of the characteristics of ‘informal settings’ is that to be logical or reasonable is enough to make one’s ideas valid. For example, he notes it is taken for granted that among peers people know what they are referring to: “We already talked about that, we already discussed that, I did not have to repeat myself.” There would be no reason to restate ideas that everybody knows, that everybody agrees on. The existence of such contexts in which assumptions are not made explicit is not a problem in itself, scientists have their own black boxes (Latour, 1987), that is, ideas that are taken for granted without need of explanation. The point here, as in other black box instances, is to understand the reasoning for turning something into a black box. In other words, how are norms established for determining what needs to be explained and what does not? In the context of this study it is hard to provide an answer. Nevertheless, the notion of moving from formal to informal settings could give some insights into that question. Such a notion represents the gap (constructed) between the self free of constraints and self in a context that sets norms for one’s actions. Accordingly, it also reflects the potential purposes of adopting such actions. The act of providing evidence would have little significance for the self, these actions would mostly represent a response to some external force/influence (e.g., a system of rules).

When we enter contexts like classrooms and the school, these contexts appear to be so stable and constant that we lose sight of the fact that to enter into the classroom
means to be in transit from outside the classroom into the classroom. Then, the notion of moving between different contexts to think about legitimization as context sensitive becomes a ‘useful’ notion to revisit that seemingly stable world. Within this perspective, participants used legitimization in a particular way that was reflective of the context they were in, even when apparently they were not moving from different contexts (e.g., in SCIED 410). My reading of participants comments about the type of evidence they used in the course to legitimate their argument is coherent with such a notion. In various instances, while constructing their arguments, participants chose their evidence based on the context of the origin of a piece of evidence. Evidence originated in the class had a greater value for legitimization than evidence coming from other contexts. That would be the case even when evidence coming from the class had little meaning for the PT, like in the Light Module for Matt:

I: So, for you, you couldn't see a connection between your claim and the evidence. But why did you choose this evidence in particular?
M: It was probably just the experiment we did in class and so we were like, well, that must be the one they want us to use but we don't know why.

Matt – Post-Light Module Interview

Or even if it implied not resolving a conflict of ideas for Conrad:

C: But I've definitely. I've seen evidence that it travels in waves in the labs of those classes. But then I saw evidence here that it seemingly travels in straight lines.
I: (...) Why didn't you put these in your portfolio[written argument]?
C: This?
I: Your evidence that you had for the other course.
C: Well, I guess because we didn't do it in here, in this class. I didn't realize we were allowed to use other stuff.

Conrad – Post-Light Module Interview

Again, by experiencing argument construction in different contexts, the sense of ‘transit’ between contexts and, consequently, of differences between contexts was recognized. Caroline, for instance talks about how different it was for her to build an
argument about light and to use the same structure to construct her web-based philosophy.

C: I think it's much easier to do evidence and justification in like, for example, the Light Module because it's like know, we knew that what we were doing in class was our evidence. You know, so we knew that, you know, that was what we were gonna use and then like justification was just kind of tying it together. Whereas, like with the philosophy, it's like there's a variety of evidence you can use. It's not like necessarily you're gonna use this experiment to explain this. You know, there's a lot of leeway in it and you have to be the judge of what you think explains it best. Whereas, like, you know, like you know during one class period, we would discuss does light travel in straight lines and we'd have those experiments that helped us formulate a conclusion. And so we knew that was gonna be our evidence. Whereas, like if you're talking about like the nature of scientific inquiry or whatever, you know, you don't necessarily have to use that. It's not like this evidence we're gonna use to show this. You know, it's like we have a lot to work with. You know, articles, like class evidence, and anything. You know, we can use anything. So there's more flexibility in it. It's also more difficult to pinpoint the best evidence you want to use, the best, you know, illustrates what you're trying to say. Which, that's what I sort of look at, well, what's the best way to say this or say that. (my emphasis)

Caroline – Post-Light Module Interview

To construct a valid argument about light involved using very specific pieces of evidence that were provided in the course activities. To construct a valid argument about your personal philosophy involved the use of more diverse evidence (i.e., experiences): “You can use anything”. Nevertheless, in spite of the recognition of differences, it is notable how differences are taken for granted and the rationale for its existence is not examined. I wonder what promotes differences in the legitimization process in these two contexts.

2.1.5 What is left out of legitimization?

So far I have presented some key concepts that were derived from my analysis of interviews with PTs. At this point, I would like to turn the discussion to the following
question: *What were other elements of the process of legitimization that could potentially have been recognized but were not?* I noted that no mention of subject matter knowledge was made so far as part of legitimization. In a science course, it was surprising that this aspect was not significant for students to make their arguments valid (despite the use of evidence and justification). For instructors, in their evaluation of the quality of the arguments, the value of subject matter knowledge was made explicit to PTs in the assessment rubrics. For instance, in the argument for the Evolution Module, representations used as evidence were evaluated considering subject matter criteria. Frequency graphs were considered representations that were more appropriate than scatter plots because the underlying concept in these representations is *change in frequency of a trait* in the population. Interestingly, the perspective of PTs on the representations was quite different. In the quote that follows, after telling me that scaffolds in the software were of little help for her to choose between representations, Caroline talks about her criteria for choosing a certain type of representation.

*C: Yeah, we… except for like the initial variation, when we first started using the software, like we hardly ever used the dotted graph, just because it was just too difficult to see any significant difference because even if some birds fell below the average, some above, and there was variation, was it like big enough variation to assume anything? Whereas, you know, the bar graph showed us, you know, like this one was this much and that one was that much and that helped a lot. Or if they were even you could really tell. So, I was hoping there might be a feature where you could like select, you know, what you wanted to do with it and then the type of graph you wanted to use. Because for, you know, you might see for, you know, number whatever or distribution whatever, you might be able to see it easier in a pie graph or a bar graph or a dotted line graph or whatever. And if you had that option, you *could try each one and see where you saw the most variation.* I think that would help when you're displaying your argument to a group of people, so they could see it easier. (my emphasis)*

Caroline – Post-Evolution Module Interview

In my interpretation, Caroline’s major concern was to be able to show differences in a clear manner, so others could see what she was seeing. Conrad, working with
Caroline, also had *visibility* as the main criterion for selecting the representations to be included in the argument. However, he experienced some level of frustration with such a criterion:

C: We didn't like the individual differences (...) We found that the distribution one were the best because when you did the individual differences, that's the one where it just plots the average line and scatters the points, I thought that we were dealing with such small differences that a little stray from the average wouldn't really show up on there. But when you did it in the relation… or, no, the distribution one, that's the bar graphs, that you could tell. that you could see trends in that one a lot better, I thought. So that's one of the conflicts, not conflicts, but when we reviewed Jared and Katie's journal, they said the opposite about ours and we said the opposite about theirs that we couldn't read their graphs very well because they did the scatter plots and they couldn't read ours very well because we did the bar graphs. So it was weird.

Conrad – Post-Evolution Module Interview

Although Conrad was a learner particularly interested and concerned with establishing connections with subject matter knowledge, this type of knowledge did not enter the arena of legitimization. And conflict prevailed... *How could one not see the clear message that I saw?* The issue of an emerging contradiction is again ignored, and other criteria for the use of representations that would rely on subject matter concepts and strategies were not explored.

### 2.2 Argumentation as means to understand

What we did is, when I said we went through and checked the heavier and longer wings and longer beaks and longer legs, or the trait that made, we made graphs for all of them and we tried to. Before we even explored any one of the hypotheses, we decided that we were gonna check them all out before we went back and picked one to focus on… or maybe more than one. But as it turned out, the beak length was the one that jumped out at us and we were running out of time, so we just kind of focused on that. So I wish I could find in
here where we did each trait. It was probably like four or five graphs in a row where we just did trait after trait to try and see which one was the trend.

Conrad – Post-Evolution Module Interview

The notion underlying the concept of argumentation as means is that participants do not always focus on making an argument acceptable. In some instances, the participants’ major concern is interpreted as finding an explanation that would better account for the problem posed, like in Conrad’s comments presented above. In this case, participants described their approach to the problem in a very different manner in comparison to Leila’s description of making it true (p. 192, in this chapter). They explored multiple possibilities, and, based on evidence, they made choices not only about what was a ‘good’ explanation, but also on how to proceed in their investigation (e.g., focus on an specific explanation). In this context, argument building is seen as means, instead of as legitimization. There is a genuine concern with understanding the problem, although, as we will see, this can have a very specific meaning in the context of SCIED 410 (and schooling as whole). Two major sub-categories were created to represent the experience of argument construction as means. It can involve, on one hand, seeking guidance in the structure or, on the other hand, sensing such structure as an impediment or constraint. Both categories are related to asking the questions: Where do I go from here? and What should I do now? To have the instructors’ structure as guidance means that the use of this structure facilitates the process of explanation(s) construction. To face impediment is to envision other ways to go about solving a problem, but feeling trapped by the structure. Moreover, one could think of the use of argument as guidance in two ways: it can guide participants actions to better pursue the problem or it can guide them in a very specific set of steps as formula. In the first case, the argument guides PTs in providing ways to approach the problem at hand. He/she is not using the structure as the path to be to get to a ‘specific answer’ to the problem (guidance as formula).
2.2.1 Argument construction as guidance for action

A good example to illustrate the notion of argumentation as guidance for action is the way driving questions helped participants focus on specific aspects of the problem to help articulate their arguments, as well as to search for certain types of evidence. For instance, in the Light Module the question did not ‘fit’ with the evidence that was provided by instructors in class. The PTs were asked to investigate *Why do we see what we see?*, whereas, in class, no experiments were directly related to the ability to see. Experiments depicted properties of the light, from which inferences about seeing could be drawn. But these inferences would have little supporting evidence. For instance, in the pinhole experiment\(^1\), participants observed how images were formed, but could tell little about how images are formed in the eye because they had no knowledge of the structure of the eye and its parallel with the experiment. Not surprisingly, all participants felt troubled or unsatisfied with the relationship between the claims they constructed and the driving question. In the Climate Change Module, when the relationship between question and claims was clearer to participants, the action of constructing an argument was described as a smoother process and more elaborated explanations were constructed.

C: Yeah, I think it was because why do we see what we see was kind of such a vague, you know, question. It was so like, you know, there wasn't like, you know, any kind of focus like what mechanisms caused us to see what we see or whatever, it's just you know why do we see what we see. And then like a lot of us had, you know, light is reflected, like light is absorbed, light is refracted. But you know those were claims, but you know if you looked at the claim and you looked at the question, like why do we see what we see, and then they see light is reflected, you know, they're like, okay, you know how does that answer the question. Whereas like “are global temperatures increasing?” You know, global temperatures are increasing or what is causing changes in global temperatures and they're like CO2 emissions are increasing? You know... I think that these questions could be

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1 In the pinhole experiment, PTs had a candle, piece of paper with a small hole in it and another bigger piece all aligned in a ruler. The bigger piece of paper worked as a screen where the image of the candle flame was projected.
answered with more direct claims, like going back to the focus, you know, gives you, you
know, more of a focus. Which in this kind of situation, I think is better because you spend
less time wondering what you should do and more time researching and looking at
information and putting in as much as you can. Like instead of, like I know Conrad and I,
we got, I know for a lot of them, we only had like one explanation page. We ended up
adding in like two or three sometimes because we were able to move quickly because we
did have that focus so we had more time to compare, you know, more maps to look up
more information and stuff like that.

Caroline – Global Climate Change Module

Caroline’s comments on how she had ‘more time researching and looking for
information’ is interpreted as the question (or multiple sub-questions) constituting the
argument also guided PTs in data collection. In the process of argument construction
those questions could be used to structure the investigation in a way that one could
distinguish what was pertinent evidence and what was not. Conrad, for instance, talks
about how the series of questions helped structure his thinking in a way that he knew how
to proceed to find what he called “right evidence”:

I liked the design of the World Watcher to be like how I said how it got you to think about
the topic instead of just letting you go to a bunch of graphs and then taking out. And it like
structured your thinking for you. So, while you could interpret it however you wanted to,
you weren't lost in finding, you know, what was important. Get bogged down in the details
of searching for the right evidence... I mean it was presented to you to interpret however
you wanted to. They didn't tell you this is what we were supposed to see in such and such
graph. But they picked out pieces of evidence that would relate to what they were asking
you to decide. (my emphasis)

Conrad – Post-Global Climate Change Module Interview

Again, when the connections between question and evidence are not clear, it
becomes challenging to construct explanations. In SCIEd 410, the question was essential
for setting the context to give meaning to evidence. If I don’t see any connection
between my piece of evidence and the question, how can I give meaning to this piece of
evidence? In the Light Module, PTs have a good sense of the piece of evidence they
should use to construct their claims – experiments conducted in class. However, to give meaning to this piece of evidence became a real problem.

M: I thought it was difficult because especially with the refraction part of it, like you were over there trying to help us out the one day and umm… it was just really difficult. Like the reflection part was easy for me to see because, you know, light bounces off of everything and so that makes sense. And refraction, like light bouncing off this table isn't being refracted towards me in any way. And I didn't… you know, nine times out of ten, light is not being refracted. So it was really difficult for me to see the application there as to how that has anything to do with our ability to see unless we're wearing glasses or something. And so that was difficult. Especially, when they put the claimer(sic!) in that like we couldn't make connections with the human eye because we didn't do any experiments in class with the eye. So. Like, even though, you know, from other classes we were fairly certain that it's true, like we couldn't really make that claim because we didn't prove it in this class with an experiment. So that even made it even more difficult to see the applications.

Matt – Post-Light Module Interview

From my point of view, implied in this challenge exemplified by Matt’s experience, was the notion that the question, somehow provided you with lenses to understand and interpret evidence. In the case of the Light Module, ironically, the lenses were turning images blurrier, instead of giving it a focus. It’s like wearing someone else’s glasses.

Another element of the structure that provided guidance for action in the construction of arguments, was the claim. In the Light Module, PTs were explicitly told to make very concise claims, presenting their ideas in sentences that reflected single ideas instead of a combination of multiple ideas constituting the explanation. In other words, PTs were asked to identify basic ideas composing their arguments and address each of those separately. To make claims more concise and focused had consequences for how participants conducted argumentation construction, guiding them to act in a certain way.
Caroline, for example, describes the difficulties she encountered in this process of making claims concise:

I: And, Caroline, any big problems that you can recognize through this process ... ?
C: Yeah, I think it was kind of like after we had done a set of experiments, I think they were the refraction experiments actually. And then we were trying to get that done and then get our argument done. And it was kind of like so much that we were trying to like narrow down and it was kind of getting frustrating. We were trying to figure out what exactly our four claims were. Because we had a couple claims but we figured out, we realized they were too long. It was kind of like we were doing like three different claims into one claim. And so I think that was the most difficult part of the process was just breaking them down and deciding what was the most important as to why we see what we see and what we could disregard or what needed to be separated to a separate claim and then just like organizing our evidence, what evidence goes with what claim and making sure our justification was clear and all that kind of stuff. So I think that was the most difficult part just deciding what our claims would be and umm trying to not put too much information into one claim. Because I think it was easy to say, we see reflected light and lighter colors reflect more light than darker colors. You know, we were kind of like is that two separate claims, is that basically like the same thing but just a different version of it. So, it was just... I think that was the most difficult part. (my emphasis)

Caroline – Post-Light Module Interview

The struggle to make claims more concise involved reexamining the way Caroline constructed ideas. She had to reflect on her central ideas and to articulate her thinking in a way that better reflected the centrality of ideas, as well as the relationships involved in these central ideas.

Others did not describe the process as a difficult one, but still they made explicit consequences making claims shorter to how they went about building the rest of the structure of their argument:

M: Well, you guys, you told us in class that we should break it down into individual claims. So that was the one change we made. (...)
I: (... ) How was the process to change your claim?
M: To change it, I thought it was real easy. Time consuming maybe but it was very easy. In fact, I think it made the whole thing easier because we didn't have so much to deal with all at once if we broke it down [inaudible].

Matt – Post-Light Module Interview

To break down the claims can guide learners’ actions in terms of focusing on specific aspects of the problem.

As we see in some instances, the reliance on some elements of the structure for guidance on how to act was identified through participant’s perceptions of the absence of such structures. In other words, there is a certain degree of confusion and insecurity involved in the process of argument construction when guidance for action is taken as part of that. *If I don’t have that, how can I proceed? What do I do?* They sought guidance but could not find it. This aspect of the concept is not restricted to the nature of questions that set the problem or to how claims are elaborated. In some cases, finding additional evidence was seen as the only way to continue constructing explanations. In these cases, the question is clear, but having elements to respond to the question become an obstacle. This type of problem can be illustrated through Conrad and Caroline’s experiences in the Evolution Module:

And then we went to check the field notes and the longer legs and longer wings. I forget which one, but one of them we thought might have been a factor. I think it was the wings. But then we couldn't find any evidence in the field notes to show any advantage that that would have... And the field notes all pointed to longer beaks being able to eat the tribulus plant.

Conrad – Post-Evolution Module Interview

We did check out a little bit of the evading and the mating to see if we saw anything else maybe that had to do with leg length or wing length. And we really didn't see much. It was actually difficult to find stuff like that related to leg length or wing length. But it was pretty easy to find stuff with beak length because, you know, eating the seeds and stuff like
that, there was a lot of information with that, especially with the tribulus plant which was really helpful because that was the most prevalent plant.

Caroline – Post-Evolution Module Interview

... because, you know, they didn't really say like whereabouts these plants were found. If they were, you know, close to the water or if they were higher up. Because I think that would of, you know, had some kind of significance or made some on our argument.

Caroline – Post-Evolution Module Interview

Working together, Conrad and Caroline were struggling to use leg length and wing length to explain the finches’ survival. They did not know how these traits could lead to survival, thus, they looked for further evidence that could guide them in their exploration of such options. That is, they believed that by looking at more evidence they would be able to construct an explanatory framework for how bigger legs would increase chances of survival and/or reproduction. They ended up abandoning such explanations, and focusing (and finally accepting) on only one of the multiple explanations that they initially constructed.

– Discipline-specific concepts and strategies in guidance for action

No examples of argument construction as guidance for action discussed so far involved the use of domain-specific concepts or strategies. Considering again my focus on science learning, I must try to see if these concepts and strategies were seen as part of argument construction as guidance. My analysis indicated that, in rare occasions, scientific concepts and strategies can have this role in PTs’ process of argument construction.

But I think that if you guys wouldn't have structured it for us, I'd say...what was the initial variation, why did the birds die, I don't know if we would have done that. Even though we knew when we did the dot lab, we saw that initial variation was important and everything, I don't know that we'd have thought or I guess I can only speak for myself, I don't know that I would have thought to check the initial variation before I went in and checked when birds died and what and where, why they died. So I probably would have left out that big part if
Conrad – Post-Evolution Module Interview

In this quote, Conrad talks about the concept of initial variation in a similar way to how he and other participants talked about questions helping them focus on what claims to construct and on what evidence to use/collect. In my interpretation, that indicates that at least discipline-specific concepts could guide action in situated argument construction.

2.2.2 Guidance as formula

C: I definitely think it was very helpful because the experiment pages guided you through like different questions, like what did you see. You know, you could put a picture there. You know, what were your results, what can you conclude. So it kind of like walked you through rather than just like, okay, you know, bring up a blank page and just explain what you saw or what you started with. And I mean, you know, eventually you might come to the same conclusion but you might get off track or whatever. There's always that chance. So it kind of kept you on track.

Caroline – Post-Global Climate Change Module Interview

There is a subtle difference between the concepts of guidance for action and guidance as formula. The first concept refers more to how elements of the structure affected how people went about solving problems. Questions give a focus to claims and meanings to evidence. Claims, when concise, help one approach a problem piece by piece (or step by step), and to identify central ideas. Evidence can guide you on exploration of hypotheses. On the other hand, guidance as formula means having clues that will lead you to a particular right solution to the problem. When we talk about ‘solution’ to a problem, frequently one thinks about an answer to the problem, focusing mainly on the content of such a solution. In the context of this study, the structure was not recognized as providing much guidance in this sense, as I will discuss later. However, the structure would tell learners about the form of the outcome, that is, what
components it should have. Matt’s comments illustrate this notion of the structure that worked almost like a template to be filled in, or a check list to be completed:

I: So, Matt, one more thing that you mentioned in here. So the difference in here is that, again, it's that we are breaking into three parts. Do you think this is important, helped you somehow?

M: Well, it's helpful that you're gonna ensure that you're not going to forget anything. If you wanted to put this into a paper then, it'd be real easy because you have all three parts that you need right there and it's just a matter of, you know, tying it all together with your…you know.

Matt – Post-Light Module Interview

By filling in the template, you make sure you are heading in the direction of accomplishing the task and getting to an appropriate solution to the problem. Through the analogy of a mathematical formula used by Leila and her comparisons between structured and open-ended tasks, I could further elaborate this concept, in terms of the processes underlying it.

L: (...) When you give me a formula, I will learn the formula and I will do the formula. And like you brought up how, you know, velocity...if you would give me the equation for finding out the pull of gravity on an object, I could do it. And if you give me like the different variables and I solve it very systematically, that's good. Whereas, when I have. I guess when I have to. Wait. Is that abstract when I have to think abstractly? Like that's like it's mathematical and then or when I have to do something that doesn't have a set pattern to follow, it's more frustrating to me then and so I try not to think like that. I try to steer away from that.

I: You mean if I don't give you the formula and just show you some set of behaviors and you have to build a formula?

2 In fact, I did introduce such type of contrast, as she had difficulty in articulating how she “normally” thinks. I compared mathematics and biology, talking about how I would feel in these different contexts of thinking, then she came with this interpretation of what would be for her to think mathematically and its meanings.
L: No, like I would rather do math than explain the natural selection. You know? So I would rather fill out progress portfolio pages for reflection rather than have you guys say, you do this and fill it out the way you would like. You know, because like I always feel like I'm doing it wrong or I'm not doing it right. Like there's a lot of lack of confidence. And even like as a student, even when like if I'm not confident in something and even if I'm doing it right, like I don't think that I am. You know what I mean? Like but if I was doing something and like it's structured and it's like just the simple structuredness gives me a sense of like confidence in what I'm doing. So that's why I think I liked the light. Going back to, that's why I think I enjoyed the Light Module more because it was more like you're doing this because, you're doing this because. You know, giving me like a reason or explaining why we're conducting these experiments.

Leila – Post-Light Module Interview

Notably, Leila’s experiences tell us about the deep impact that guidance as formula has in the process of argument construction – some people can barely function without such guidance. To leave it open-ended means to give room for mistakes. Moreover, her comments bring to surface the connections between form and content in the outcome:

I don't know, like... the only thing I can really say and I'm sorry, but like I didn't like the natural selection thing because I didn't feel like I was ever doing anything right. Whereas, with the light, since it was a little more structured, I felt like. And I know you're gonna say, well, you know, the electronic journal and the natural selection and the Bguile software, like that was supposed to help keep us structured. But at the same time, we were the ones who were entering in the claims that we were making. And if we’re making wrong claims but we still were like entering in the information, like we could have gone a whole module without even knowing that we were doing it wrong. Whereas, here, you know that you're no... you know if you're talking about reflection, you're not supposed to... like light's not supposed to bend when you're talking about reflection. You know? So like it was just like a way to double check like what you were doing. So I felt more comfortable with that.

Leila – Post-Light Module Interview
The aspect that I would like to emphasize in Leila’s comments is that, frequently, PTs refer to the argument structure solely as something that will set the form of the argument, as in Caroline’s and Matt’s quotes. Although no mention to content is made explicit, in those cases, Leila’s comments provided a great deal of insight into the relationship between form and content of the outcome. My reading of the latter quote is that the *structure* guidance on form, though important, could not stand on its own. For her, it would be helpful only if guidance on content (that *did not* come from the structure of argument construction) was provided.

### 2.2.3 Argument Construction as Impediment

Interestingly, in spite of the impact that guidance has in argument construction and the way it is perceived as extremely important, argument construction was also experienced as limiting. The structure did not always facilitate the development of explanations. As defined earlier, to face *impediment* is to envision other ways to go about solving a problem, but feeling trapped by the structure. Such an experience with argument construction involves a sense of being turned helpless, instead of being helped by the structure.

L: Well, like I feel like this semester, we dealt a lot with like an inductive method of inquiry. You know. And like sometimes the deductive way is better. Like for certain topics. You know, like it's just. And it's all personal preference, I guess. Like the way you learn. I guess.maybe I'm more of a deductive. But like I can do both. It's just sometimes it got very annoying sticking to the same pattern because it just got very monotonous. Especially when you have a long class because you're just like doing it. You know. But it was. I can definitely see how it was helpful like to use teachers like to keep order in the class. Like I can definitely see how that was helpful, but…I have mixed feelings on the whole thing. I do.

Leila – Post-Global Climate Change Module Interview

The notion that this process “got very monotonous” is an important aspect of argument construction as impediment, because it implies that it is a repetitive process that one has to follow. Thus, the *choice* of a way to construct explanations appears to be
associated with the notion of constancy and repetitiveness. Again, by just repeating a procedure, new insights on the problem were not generated:

M: Okay. It just seemed like it was the same thing over again and I didn't really... I didn't make any further connections or further understandings from doing the argument part of the portfolio in answering the question. It was just like it was copy and paste it seemed. Umm... If I got further understanding from it or was able to make connections better?, I would say it was good to use it, but I really didn't.

Matt – Post-Light Module Interview

In summary, to construct an argument is experienced as a sterile process, a mechanical repetition of procedures that results in no meaningful outcome. These experiences, again, turn our attention to that question raised before: What is missing in that experience with situated argument construction? In relation to the specific case of this category, I see PTs telling me that there is something missing in their experience. However, it is hard to determine what could be missing. Based on participants’ comments, I would say that it was expected that the process of argument construction would involve some level of creativity and flexibility. But what would creativity and flexibility look like in the context of argumentation? It’s hard for me to tell. I wonder if participants have a vision of this? Did they have experiences outside SCIED 410 that would reflect those ideas and feelings? So far, the process of argument construction has been described as a process of following paths that are well-established (legitimization) and paths that are pointed (guidance). However, this situated argument construction does not include transgressing paths or constructing new paths. As an educator and researcher, I cannot ignore such an absence.

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2 Bauschipes (2001), talks about well-travelled paths and fences to characterize mathematical education.
2.3 Argument Construction as Legitimization and Argumentation as Means to Understand: Shifting Meanings

When one thinks about the two categories that we used to characterize processes occurring in the context of situated argument construction (i.e., argument construction as legitimization and argument construction as means) he/she should be aware that I intended to represent those categories as distinct, but still closely related. As I examined the participants’ interviews’ excerpts, such a relationship could be identified in two manners: (a) both categories can occur in the same investigation at different times; (b) particular processes that at some point had one meaning (e.g., guidance) could later acquire a different meaning (e.g., legitimization).

Well, I guess that more relates to just this program that we had to first generate all the graphs and then from those we formed a hypothesis. And then we went through and tried to test it. By testing it, we just checked out the graphs of all the different options and saw which one was the most prevalent. And then, at the end we had to do the presentation and we have to hand in the final journal and that's gonna be our conclusion. So that you can’t just. I guess it's showed me that you can’t just say something without backing it up. We actually had to gather the data, say something, and then back it up and explain why we thought so. But that was a good thing... a good way of showing what scientists do.

Conrad – Post-Evolution Module Interview

In Conrad’s story, I identified two distinct phases. First, when they were exploring the problem they used the structure more to guide their actions (e.g., generate hypothesis, examine evidence, test hypotheses). Then, they would think about how to present their argument and their journal, focusing on legitimization of their explanations (e.g., “back it up and explain why we thought so”).

A similar process of shifting from guidance to legitimization or vice-versa, happened as the course progressed and PTs participated in different modules.

M: I think with the Light Module it was look at the evidence until you find out what the claim is exactly. And with this, well, it's the same thing. Because in this one you're looking at the evidence until. Or in this .no, in this one you're gonna .it's like a back and
forth and I'm gonna look at the evidence, finalize what my claim is and then go back to the evidence and pick and choose the evidence that's gonna support my claim best. That's gonna best support my claim. Because, obviously, I think there's gonna be some that's better than others.

Matt – Global Climate Change Module

In my opinion, however, it is in the Evolution Module that these shifts are clearer in the experience of both pairs. Conrad and Caroline, as described above, started the module exploring multiple explanations systematically. They were primarily engaging in guidance for action. They found an explanation that was more promising and they further explored this explanation. In my interpretation, at this stage, they were still engaging in the process of argument construction as guidance, because they were aware of the existence of other possibilities and their limitations and/or strengths. In other words, they were still searching for understanding. It is only at the very end of the module, when they are asked to evaluate and then present their argument, that they shifted to justification. In this situation, for instance, they decided to ‘discard’ (i.e., considering) explanations that could not be fully explored. On one hand, they recognized that there was a difference and the data was inconclusive, but on the other hand, they simply considered the same explanations as proven wrong. The other pair engaged in legitimization earlier in the module. At the very beginning, they were trying to address the problem, but they struggled to find guidance in the context of the Evolution Module. They would try different things in a random way, being confused and lost. Then, somehow they found an answer, which changes their behavior – now they know where to go. They adopt a systematic way to approach data centered in legitimization, that is, to make this question acceptable to other people, in particular the instructors. In summary, my understanding of the context involved in shifts from legitimization to guidance in both pairs, involved a movement from searching for an answer to having an answer to

4 Leila’s and Mike’s accounts on how they got to the idea that differences in beaks were responsible for the survival of the finches are considerably contradictory. Sometimes they said they found it by constructing graphs, sometimes they said someone told them, sometimes they just say ‘we knew it’.
work with and needing to present or convince someone of the value of the answer. Interestingly, to convince, they have to show this answer as hegemonic.

Another interesting aspect that needs to be further explored is that meanings of specific aspects of the process can shift from one situation to another, being aspects of legitimization or of guidance, depending on the context. An example of such a change occurred when instructors included new elements to the structure that further explored such relationships, and some of the participants were able to further reflect about these relationships. Interestingly, this reflection resulted in changes in the meaning of this relationship in the process of argument construction. If the question – claim relationship initially involved, in my interpretation, guidance for action, in the context of the structure it became an issue of legitimization.

Like, here, in this module, you were asked to do this and relate each claim back to the question and explain how it responded to the claim and the question was related to the claim. Was it helpful?

C: (...) Yeah. Like, at first, like every box that we did I was thinking when I got to the bottom like, oh, we have to do justification, we have to type the same thing again in the box below it. But then when we got to the box below it, it like suddenly became clear that it wasn't the same as the justification, that we had to somehow tie. It's really tough. Like, for some reason I had never realized that in any of them until we got to that point when it said to me, our claim relates to the driving question and then we had to go and put in a question. I think putting in the question was the key there because that made us. (...) I think that's what you then need to realize that our claim can’t just stand on its own, it had to be related back to a question... to one of the questions to be significant. And we couldn't just assume that because we said so, some of them would relate it on their own.

Conrad – Post-Global Climate Change Module Interview

In Conrad’s comments, I don’t see the question – claim relationship being used to guide his actions in constructing his explanation. I see him using this relationship to make his argument more acceptable: “our claim can’t just stand on its own, it had to be related back to a question...” In this example, we see how when reflection about the relationships became a task, the PT turned the issue of guidance more into an issue of
legitimization. In my opinion, the example, presented above, carries an interesting message for educators. As we perceive legitimization as a more limiting process for learning, because the meanings of argument construction are driven by external and not shared norms/criteria and understandings, the question becomes what educators can do to reduce the emphasis on legitimization. Educators should be very cautious and thoughtful in that respect, since their actions have a great load of ‘authority’ that reinforces legitimization. When we, as instructors, asked for something to be done (or when we try to ‘model’ certain behaviors and attitudes), portraying something as important the task/aspect/behave can immediately acquire a meaning of legitimization. A meaning that is so strong that it overwrites other more personal meanings that were constructed through lived experiences, which were much more important for the self, but that quickly acquire a secondary significance in face of authority. In other words, the questions that emerged for me from these shifts in time and shifts in meaning are related to what is going on to promote such changes.

3 Mapping concepts into the context of the tasks

Considering the fundamental role that instructors played in defining the context for occurrence of the process of argument construction, I believe it is essential that we explicit identify some of the relationships between the context of instruction (or the tasks PTs were involved in) and the movements from legitimization to guidance. Throughout the data analysis, I (as well as participants) draw comparisons between modules, which permitted me to identify some patterns and propose some relationships.

In my interpretation, legitimization was prevalent particularly in the Light Module. What are the characteristics of this module? The module was designed expecting that participants would come with a series of misconceptions about light (alternative explanations) and by following a path that was determined by the instructor, PTs would discard these alternative explanations and adopt the scientifically accepted explanation. Notably, the path to the scientific accepted explanation was clearly defined
with virtually no possibilities for ‘transgression’: PTs were given only pieces of evidence that could clearly illustrate this explanation; they followed a sequence that would lead them to address only certain aspects of the problem, and they were not given any alternative explanations to explore. Moreover, all the pieces of evidence were experimental evidence. In sum, the Light Module had some of the key elements of legitimization. First, it conveyed a single clear message, by using unambiguous evidence and not providing room for multiple views (or conflicts). Second, it was the ‘most concrete’ module, always presenting physical evidence for the ideas built in class. In my view, without being conscious of that, we created a module that would provide our students a good example of what is to teach as legitimization. Naturally, this would have great impact on PT’s experiences in constructing arguments. Furthermore, guidance for action partially failed in this module, since the question would be confusing instead of helpful for students in this context. However, we should note that making claims concise supported students in articulating their ideas. It would be important to better understand this process, and to what extent it impacts the process of argument construction. In my interpretation, it had little impact in shifting the focus from legitimization to guidance in the context of the module, indicating that various elements need to be combined to create a situation for guidance.

As I noted earlier, the Evolution Module was particularly interesting in the sense that it involved movement from legitimization to guidance for action. Notably, this is a module in which guidance for action occurs most frequently, involving different aspects (e.g., question, evidence), and the use of discipline-specific concepts and strategies, (although rarely). In my opinion, this module illustrates the potential of curricula and software designed to support students’ scientific inquiry that is informed by notions of argumentation as well as discipline-specific knowledge. However, I still identified a predominance of processes of legitimization when I examined participants’ perspectives. This raises the important question of *What is promoting legitimization across all the modules?* The comparisons of pairs’ experiences discussed in the previous section could shed some light on this issue.
Finally, in the Climate Change Module, guidance for action did occur, but basically in respect to using questions to focus. This is an important aspect, but it’s impact may not be as significant as other types of guidance, as we will see when we examine PTs’ perspectives on learning.

4 Situate Argumentation as guidance and as impediment: emerging tensions

I already recognized the importance of the apparent contradiction between valuing (and needing) guidance in argument construction, and, at the same time, experiencing the constraints that may derive from guidance. I revisit this aspect once more, to connect it to the issue of legitimization previously discussed. This tension reflects, in my view, the transit from the experienced context(s) and contexts of possibility (or alternative imagined contexts), hence, their value for the present research. Does that tension reflect a challenge to argument construction per se? Or even a challenge to more fundamental elements of science education, schooling and learning per se? Is guidance that far apart from legitimization? How is the very process of ‘legitimization’ that they have to accept being put into question? To better respond to these questions, argument construction must be examined in a broader context. PTs experiences have to be seen not solely as processes that take place as one constructs arguments. These experiences are clearly related to the purposes involved in engaging in those tasks and what is gained from participating in those processes, and how one positions her/his self in relation to the situated argument construction (see for instance the quotes from Caroline on p.228, and from Matt on p.229). To explore this aspect I chose to focus on the relationships between understandings of the process of argument construction and participants’ perceptions of learning in the context of this process. Concepts related to perspectives on learning and its relationships will be further developed in the following section.
5 Perspectives on Learning

5.1 Introduction

Initially, in this study, I believed that I would only be able to construct understandings about the experience of learning science through argumentation. As the analysis progressed, unexpectedly, I realized that I would be able to develop a response to questions that, at the beginning, I did not envision as possible. The research question, What were perspectives on learning that emerged from the experience of situated argument construction? is a good example of the process of reformulating research questions, and how a completely new question can emerge during the process of data analysis (Charmaz, 1990).

Furthermore, the interconnectedness between research questions became more evident to me, particularly in the case of this second research question. As I constructed an answer for the first research question, I became gradually aware that the study was not about learning through argumentation only. The instructors, including myself saw learning occurring, but PTs did not perceive their experience of situated argumentation as a learning experience. I started to see PTs’ experience in SCIED 410 as an experience in science education, instead of an experience of science learning. In the specific context of situated argumentation, PTs were more students than learners. However, at the same time, I could see that learning was occurring in the broader context of SCIED 410, and, more importantly, the participants were saying that they were learning science in the course. My reaction to this observation was to inquire about the particular circumstances in which learning was occurring from the perspective of PTs. One of the consequences of examining the data with this particular question in mind was that I was able to have access to some of participants’ perspectives on what was learning at school, and the role of the teacher, without initially intending to do so. Some of these aspects already emerged as I addressed the first research question (e.g., that knowledge is not seen as socially constructed), but now they came together and are interrelated through the notions of learning.
In this section on Learning Perspectives, I will provide a representation of participants’ perceptions of learning by addressing four aspects of learning: (a) What is perceived as the outcome of learning?; (b) How does one know learning is taking place and what are the perceived characteristics of a teacher who promotes learning?; (c) How one decides that learning took place?; (d) What were the types of experiences, particularly the sources of evidence, that are perceived as promoting learning?

5.2 Prospective Teachers’ Perspectives on Learning

5.2.1 What is the outcome of learning?

When asked about learning in SCIED 410, all participants talked about situations in which they acquired new information. Notably, information referred to very specific pieces of data, like numbers, but also could refer to specific concepts. This was particularly illustrative in the context of Conrad’s and Caroline’s experiences in the Global Climate Change Module, as represented in the following quotes:

I: And I was wondering if you could find me some things that you learned from that. From building the argument.

C: Well, one thing that probably I kind of knew, but wasn't. See, all this stuff was kind of like there in my head without knowing what it was or how it related. But human production of carbon dioxide is a lot worse than I thought it was. Like I knew it was bad and we shouldn't be doing all the stuff we're doing, but when you look at countries like the United States and China and see how much carbon dioxide they're putting into the atmosphere it becomes real significant. And that was probably, as far as learning goes, that's probably the thing I learned most, that humans are probably the cause. But I'm still not convinced entirely that there's anything we can do about it at this point. So maybe it's already too late.

Conrad – Post-Global Climate Change Module Interview

And I also learned a lot about specific countries, like which countries are, you know, emitting the most CO2 and stuff like that. And I was really surprised to see that like our
area, like near Pennsylvania, that's like pretty high up there. And umm... I didn't realize that. I was thinking more like China... like China and Japan, I know those areas are like, you know, pretty high too, but like for some reason I just thought they would be more so because they are so like heavily populated and, you know, they do have like a lot of like factory production over there and whatnot. But then also, I guess you could take into consideration like it doesn't seem like as many people drive cars over there and stuff. Well, from what I know. I've never been there, but from what I hear and what I learned.

Caroline – Post-Global Climate Change Module Interview

Leila, on the other hand, illustrates an example of learning a new specific concept, and how holding the new information would permit her to transmit it to other people:

L: Because I always used to umm... like I never really knew the difference, like what umm. .... the ozone depletion effect was. Or like, you know, I knew that the ozone was depleted or whatever. I didn't know what it did. I confused... maybe not confused, but I didn't fully understand what the greenhouse effect was. I knew like what it was because of what a greenhouse is, like a real greenhouse. Now I know like... like I feel like I can go out and like have a debate about it with my Dad. Like I can like, you know, state some facts that I know. (my emphasis)

Leila – Post-Global Climate Change Module Interview

In my interpretation, this indicated that the outcome of learning was seen as an answer to the question – information that could be accumulated and transmitted. This became more evident to me in Matt’s comments, like the one that follows:

I: Matt, my question was more like about your perception about feeling, okay, I feel that I know that or I feel I don't know it or I feel I know it a little.
M: Okay. I feel I know it then. Sorry.
I: And what makes you feel you know it? It's just like.
M: Being able to answer a question, like I just did.
I: Okay. Okay, that's important because that's something that I wonder about.
M: If I answered it correctly.
I: Okay. So, once you now look at this pre-test and you feel, okay, I can answer all this. So you feel confident that you.
M: Yeah. And I think the other indication is that I can go through and find where my errors were before.

Matt – Post-Light Module Interview

This quote from an interview with Matt illustrates various aspects of learning as having the right answer. My reading of his words is that to know something means to be able to provide answers, these answers have to be the right answers, and you are aware of what the wrong answers are. This perception of learning was, in my opinion, clearly reflected in his experiences in SCIED 410:

M: Well, that's what makes me feel I don't understand it because like... it just seemed like after everyone was done talking, after the discussion was over, there wasn't really an answer.
I: And you mean you couldn't, yourself, give that answer.
M: No, not really, not confidently.
I: And you feel you needed like J to organize something with the class as a whole group, like a closure to make you feel I know the answer.
M: There was like no conclusion like to the experiments. That's the best way I can say it. Like there was no conclusion. And you say, okay, well, that's what it is, you know, you're right, you're wrong and... I don't know, you can't say you're right, you're wrong, but.
I: Kind of a consensus.
M: Yes, there was no consensus. (...) And it was just kind of like, well, what do you want to make of it and then. I don't know. I just didn't feel confident at any point.
I: You needed this closure.
M: Yeah. For instance, all through the presentation, I wasn't confident with it and it just seemed like I was waiting for that one question to come that was just gonna sink us and I was just gonna say I don't know, you know, you got me. And like that's literally what I was waiting for through the whole presentation was just someone to ask a question that I didn't know. And fortunately, it never came. So maybe I did know it well enough, but it didn't seem so.
I: You didn't feel like.
M: It didn't feel like I knew it well enough.

Matt – Post-Light Module Interview
However, other participants did not express so clearly a notion of learning as having the answer as Mike and Leila did.

5.2.2 How does one know learning is taking place?

In my interpretation, for participants, learning is taking place when they have a sense that they are going in a direction to find a specific answer. All the participants talked about the importance of being on the right track for learning. This is illustrated through the following quotes from Conrad and Caroline in the Climate Change Module:

C: Yeah. I always found myself asking which one of these categories does this graph fit into. Like that. So that would be my first inclination. Now, after doing all the activities they tell us to do, I would try and decide which category it fit into. So a combination I guess of the guidelines that you gave us and the way that the world watcher software was set up really like narrowed down and eliminated a lot of like stuff that would have probably wasted time and got us off track.

Conrad – Post-Global Climate Change Module Interview

I liked this one better. Like I liked the way this one was set up better. I don't know why. I found it easier. Like the progress portfolio gave us like direct guidelines, I think. You know, like you know put this is what driving question is this answering, what's your claim, your evidence, description of evidence, justification, and why it relates to the driving question. Like I liked the way that was set up because it kept us like focused and like on track and helped us like organize all of our ideas and decide what to put where and we wouldn't have to worry about like messing anything up.

Caroline – Post-Global Climate Change Module Interview

However, the complexity of this notion of being on the right track is better captured through the comparison of Leila’s and Matt’s experiences in the Evolution and in the Light modules. Leila had a better learning experience in the Light Module as she describes in the following quotes:

L: Yeah. I felt like. I liked the way we built our argument with this [the Light Module] because I felt better about it, like we were on the right track. You know, like I felt like we,
like Mike and I, were like moving in the right direction as far as .because like, you know, he presented why do we see what we see, like that's the driving question and then as we were doing each experiment, we knew that it went back to answer that question and so in a sense it nicely structured our argument because we had these .like we did the four different experiments. But I felt better with it.

Leila – Post-Light Module Interview

I: Like, when you say right track, can you help me to understand? Because I might later interpret that, so I would rather have you tell me that.
L: Oh, no, that's fine. That's fine. With the finch module, Mike and I were on the wrong track for a very long time and with the Light Module. I'm sorry, the wrong track meaning we were not.
I: Getting an answer?
L: We were exploring wrong things. Everything that we were doing was not helping us. You know what I mean?... Like it was not... And so that is what I mean like wrong track, like we weren't doing anything positive for our problem. Whereas, with the light, even if we were unsure about what we were writing, at least we knew that it had a direct impact on why we see what we see. At least we knew that it was something that is important for our argument.

Leila – Post-Light Module Interview

I don't know, like. the only thing I can really say and I'm sorry, but like I didn't like the natural selection thing because I didn't feel like I was ever doing anything right. Whereas, with the light, since it was a little more structured, I felt like... And I know you're gonna say, well, you know, the electronic journal and the natural selection and the beguile software, like that was supposed to help keep us structured. But at the same time, we were the ones who were entering in the claims that we were making. And if were making wrong claims but we still were like entering in the information, like we could have gone a whole module without even knowing that we were doing it wrong. Whereas, here, you know that you're not... you know if you're talking about reflection, you're not supposed to... like light's not supposed to bend when you're talking about reflection. You know? So like it was
just like a way to double check like what you were doing. So I felt more comfortable with that.

Leila – Post-Light Module Interview

Leila, talked about being very confused in the Evolution Module, and her constant concern at this time about her investigations reflecting something that was wrong and would not provide an answer to the question. Matt’s experiences had strong parallels with Leila’s but, interestingly, the perception of the modules are notably different.

M: The finch module, after we did it, it seemed like we like broke it down and P [the instructor for the Evolution Module] would say, all right, now this is why it happens. You know. And with this one, it was just kind of like, well, you know, we showed that light bent, but it just seemed like he never really came right out and said, you know, the reasons for why this is happening or anything. He tried to get us to say it all. And it just wasn't... it just didn't seem to be clicking for a lot of people, that method. So I think on J's [the instructor for the module] part of it, maybe he should have... he should have discussed it more openly, just came right out and said, you know, at some point, you know, this is what's happening after we had discussed it as a group. Because it was kind of like, well, we discussed it as a group and everyone threw their ideas out and it was like, okay. And then if you would ask him, well, you know, maybe there's two ideas that seem like they could work, like I don't know, idea A and B, if you would ask him, you know, which one of those is right, he would say, well, ‘what do you think?’ And it would just kind of get beat around the bush and then at the end you're... like then at the end, you think you understand it and you sit down and you're like, no way. Like... do you know what I mean?

Matt – Post-Light Module Interview

I: I mean during the finch presentation, you felt like, I know that.
M: Yeah. Definitely.
I: People can ask me questions and I can answer them.
M: Yeah. I felt much more confident doing the finch presentation than I did the light.
I: And what was going on there?
M: I don't know. That's what I've been trying to answer. I don't know.
I: Yeah, I know it's so hard because I think about that. But it's so hard.
M: It just seemed there was a conclusion to everything that we learned in the finch module. So, all we were doing then was trying to apply. We were just trying to like use what we learned and it just didn't, like there was closure to those ideas and it just didn't seem like there was any consensus for a conclusion.

Matt – Post-Light Module Interview

I: So, in this module, Mike, it seemed that in the finch module that, to me, like you kind of didn't discuss the answer, you didn't know if you were right. Did you?

M: I think we did... Like, as far as the information that was available to us, we knew we were on the right track.

I: How did you know that? I mean there was no closure before the presentation, that is my point.

M: Umm... well, the fact that when you're talking to other people too and like outside of class and you know they have the same answer, that's reassuring.

I: You mean the peer review?

M: The peer review and then like you go over and you look at someone else's presentation and they have almost the same conclusion that you do with, you know, a little twist here or there. When you talk to people like, you know, waiting for the bus outside.

I: Yeah, informally.

M: Yeah. And umm... that was reassuring and it helped with confidence. But I mean when you look at the evidence, there was really no other answer that could be like. I don't know. When you looked at things, you just kind of knew that it's not that, it's the beaks.

I: You felt you understood the.

M: I felt I understood it. And it was like the evidence made sense to me according to what we learned in class. I don't know. Like, the same thing with the light. But it was just something. I'm sorry.

Matt – Post-Light Module Interview

It was very interesting to me to see how two people could perceive the same module so differently, and at the same time, I could see that similar perspectives underlie the different perceptions. For Matt, the Light Module was the module in which he felt he was not on the right track. As we talked more about his experiences, it became evident to me (see last quote) that what provided him the confidence he had in the first module, was
that he knew his answer to the problem was right (by talking to his peers). Note that for Leila, it was also the fact that to some extent she knew the answer (e.g., it’s about reflection) that kept her confident during the Light Module. The difference between the two is that Leila had this concern throughout their investigations, whereas Matt talked about this type of concern with knowing the answer only later in the modules when he had to give the presentation.

On the other hand, Conrad and Caroline never talked about having experiences of being on the wrong track. Thus, it is hard to have a good grasp of the extent to which they were concerned with knowing the right answer. In other words, for these participants, the idea of being on the right track did not necessarily imply a focus on the right answer. However, I think that in saying that there is a right track it is implied that one wants to get to a solution and that it is one of the most important aspects of the learning process – if you are not in the right track you will not get anywhere. For instance, to find out that a certain explanation is not a valid one does not imply in learning – you would have to find the right one and discard the others. Moreover, to find out ways to go about a problem without finding a clear response to the problem would not be learning either.

- What are the characteristics of the teacher who promotes learning?

Through the categories promoting learning through guidance and promoting learning through answers, I intended to explore another aspect of learning that I identified in the data and that, in my opinion, is directly related to the others: From the participants’ perspectives, what would be the role of those who promote learning in the context of school? In other words, what would be PTs’ expectations and recommendations on how to promote learning? It is particularly in this respect that differences between the two pairs became clearer. In my interpretation, on one hand, Conrad and Caroline focused more on the importance of teachers providing guidance. My dialogue with Conrad in the Global Climate Change module illustrates first how he
valued having the teachers providing structure\(^5\), then I asked him to imagine how it would be like if this structure was absent.

C: I don't know, I felt this one was... this module was a lot more structured like. And I kind of contradict myself later on when I show you my philosophy. But while we had the freedom to interpret the data however we wanted, it was more like follow this path and look at the data in this order. But maybe not even in an order, but umm... I said it guided our activities [inaudible] Like in the other modules, we had to pick, like for the finch module for example, we could pick which... like we had to narrow it down to beaks and then move on from there. But this one kind of... there wasn't really a right answer. I guess there wasn't a right answer in the finch module either, but. Do you know what I'm saying? I'm saying like it guided what we were gonna do instead of. Like, I don't know that we had an approach as much as we followed the approach presented to us by the software.

Conrad – Post-Global Climate Change module Interview

I: And let me ask you something. If I gave you the question, because that's something that I thought about, if I gave you some questions and you were aware of the data that was available, do you think... how would it work for you to have to design specific investigations and comparisons?

C: You mean if we were just given like a list of graphs on these four questions?

I: Yeah.

C: Well, I think it would still work. Definitely still work. But this kind of cuts out the grunt work of it. Instead of going through like... Well, that's all on this thing out here with the extra graphs. There's just a lot of graphs. Is this what (...) And this would take a long time to go through. And we probably wouldn't do too much. [inaudible] I don't know, does that make sense to you?

I: Yeah.

C: All right. It probably... it might have helped. It might have been good for us to search for it. But as far as time goes, I thought this was a good way to do it too to give us what

\(^5\) Note that the structure in this case is not the argument, but how the investigative activities were designed.
was relevant [inaudible] interpret it. I didn't give us the option to go look for more if we needed to be convinced further.

Conrad – Post-Global Climate Change module Interview

Caroline would talk in a similar way about the structure of the Light Module:

C: The experiment was definitely the big thing. But I liked the way he kind of gave us like a packet to kind of like guide us along when we were doing it. Like the packet where we had to construct the ray diagrams. And then like he walked us through the process of like making, you know, hypothesis. And then, you know, we compared our hypothesis to like the actual results in the experiment. And so we were able to take that information with us back to the computer lab so that we could use it when constructing our experiment page. And I think that was helpful because a lot of times, you know, you might forget things along the process. You might not remember what you originally started with and then you just kind of think back to... you know you just kind of remember the ending result of the experiment.

Caroline – Post-Global Climate Change module Interview

Notably, in all of these quotes participants’ mention the instructors’ role as providing answers to students. In fact, I see Conrad valuing specifically the opposite in various instances such as the following:

C: I liked the world watchers set up. Like I said, how it guided you instead of told you what to do or how to interpret. So I would definitely use that.

Conrad – Post-Global Climate Change module Interview

On the other hand, Leila and Matt, appreciated guidance from instructors (or instructional tools) but they expected more from instructors. I inferred this from their comments about learning experiences both in SCIED 410 and in the past. Leila, for instance, made explicit how she saw the role of the teacher in the classroom:

L: Well I'd like to believe that my teachers like ask good things. Like I know... like I do have a mind of my own, but when it comes to the classroom, like I take what the teachers say with a great deal of like, you know, they're telling me the truth or they're telling me, you know, what I need to learn because they're in charge. You know. So, maybe that's the
wrong attitude to have sometimes. But, yeah, I usually take what teacher's say at face value. (…)

I: I mean you usually when something doesn't make sense, you usually [ask questions].

L: Yeah, definitely. But for instance, like I wouldn't. like I wouldn't have struck up an argument with J [the instructor for the Light Module], being like, J, light does not bend, J, I don't see light bending. Like he obviously knows more than I do about the subject and so he... like you know he plays a different role than what I do. Like I'm the learner and he's supposed to inform me. So in that respect, that's how I approach classes. But, yes, I would definitely speak up if I felt like something was wrong. I definitely would. So, you watch out.

Leila – Post-Light Module Interview

My reading of her comments is that she saw the teacher as holding the true knowledge and being the person who should decide what happens in class. This view, in my interpretation, is very coherent with what would be her expectations of a teacher:

if a child came to me with a question, I would assess and see how much the students... like because I feel like sometimes in this class, not just me alone, but like with my peers in the class, like a lot of us were clueless when it came time to do the projects. And, you know, if we would ask questions, sometimes we would just, you know, we would not really get a tangible answer. We would just more like just get like a nod of the head or... sometimes it would... I think in an effort to make us think on our own and make us investigate things on our own like with the inquiry, in an effort to like do that, I think a little bit of... I think something was lost along the way because I know a lot of us were confused and like totally clueless and that's frustrating when you're trying to do a project and you know that like the project is due, you know, the very next day and you still don't know what you're doing. And so that's a little frustrating because... you know, maybe this might just be like the freshman in me, but like students turn to teachers for guidance and like even though like this module was very helpful, sometimes I felt like we didn't really receive an answer to all of our questions. And I know that sometimes we're not supposed to because it does make

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6 Here, I challenged her based on what I knew about her behavior in class: she usually was an active student who would not take what we would say at face value.
us think. But there was times where I was just like... I wasn't helped and so I got a little more frustrated.

I: So, with students you would help them more and maybe as they start their projects.
L: Yeah, I would .like... yeah. Because like if I would be a science teacher doing this module, I would definitely help the students. I mean I wouldn't probably give them the answer right away. You know, like I would definitely guide them towards the right answer. But I would guide them towards the right answer. Like... like I would be there to make sure that like they were at least getting started. You know, like giving them a starting point. I kind of felt like that lacked. (my emphasis)

Leila – Post-Light Module Interview

Matt’s ideas would be very similar to Leila’s about what teachers (and instructors) should do:

I just felt like a lot of our questions weren't being answered and that was really frustrating. Like I know it's an inquiry based teaching method where you don't just give them the answers, but I think there comes a point where you can't just keep. like... J [the instructor for the Light Module] just kept asking why. And it gets to a point where you can’t keep asking why anymore because you're just not gonna get there. You're just going around in a big circle and you're never gonna get to the point. But you need to make some change to lead them in that direction or just flat out tell them. And I don't think all your efforts, inquiry wise, are gonna be just wasted because you have all this other experience in that you can go back and say, oh, that's why, you know, and relate it. Do you know what I mean? Like, I just felt like he was trying. he was trying to get us to answer our own question, which is good and I think that's a good approach to it, but it wasn't working. And like I said, it comes to a point where you just need to stop and say, okay, here's the answer or change something with the way you're presenting, going about trying to introduce things to make an alteration as necessary. (my emphasis)

Matt – Post-Light Module Interview

Again, his views of an inefficient teacher are coherent with this notion of what teachers should do to promote learning. This is illustrated through a negative past experience he had:
I: Okay. And this physics guy, why do you think he was a poor [teacher]?...
M: He was very disjointed from the class. Like he would give us a lab to do and send us off to our computers and he'd play computer games. And umm... he would teach like two days out of the unit, like actually like just teach. And the rest of it was just like, well, you know, read the book and try to figure out the lab on your own. It was the closest thing to inquiry based education that we had. But if he was going for inquiry, it was really ineffective because it just left us like... it just left the class in like anarchy, like trying to just get answers any way you could. Like if you had to like con the answer out of him, like just talk it out of him or something and then give it to everybody else in the classroom. It was just like get it done however you can because no one had an idea of how to do it. And it was just really frustrating.

Matt – Post-Light Module Interview

5.2.3 How does one decide when learning is taking place?

The most prevalent notion among participants, in my interpretation, was that learning involved establishing a distinction between the correct understandings and inaccurate understandings. Here, I identified parallels between being right and holding a scientifically accepted understanding and, accordingly, between being wrong and holding understandings that are in conflict with the scientific accepted answer. The concept learning as telling right from wrong was developed based on experiences that PTs’ described as learning experiences, in particular, those that were the most important in their development of new understandings.

For all participants, most of their learning occurred through the reading assignments on conceptual change. The following quotes from Caroline and Leila were used to illustrate the meaning of these experiences.

I: Give me examples of things that you did in class during this period that helped you to learn about that.
C: Well, when we read about common misconceptions, that actually helped because, you know, I read that a lot of people had the same misconceptions that I did and then that
article kind of, you know, introduced me to, you know, what umm... like what the misconceptions were and what, you know, the real answers are.

Caroline – Post-Evolution Module Interview

C: Yeah, I definitely. you know, I definitely think I learned a lot. Like especially, you know, like clarification of what, you know, the greenhouse effect is. I really found it interesting that one article we read about misconceptions because, seriously, that is like a really big problem because I even link, you know, the ozone layer depletion with global warming and I mean. I think I wrote this in my misconceptions article, but like last semester I took Earth II and like our goal in that class was for our instructor wanted us to decide how we feel on the issue of global warming. And even then, like when, you know, Conrad and I came in and we were discussing what global warming was, even then I brought up ozone layer depletion. I mean it's just, you know, it's really, you know, odd how that really does happen. And I mean like so I think, you know, I had a good general idea of what global warming was, you know what scientists said it was and how it was caused but this kind of, you know, this module gave me a real good clarification of what it was. So like if someone asks me to explain it, I think I could do a pretty good job of explaining it or at least giving a pretty good general explanation.

Caroline – Post-Global Climate Change module Interview

I find it funny that... Because like, for example, like my cave salamander example is totally, totally wrong. And I was like elaborating so beautifully on like how wrong it is. But umm.... but I know now that that's wrong. Like the Bishop and Anderson article was very helpful with that.

Leila – Post-Evolution Module Interview

L: Even in the Light Module, like I got my best insight or I understood things better when I read them. Like the articles that we had to read, they always helped me. Like they always just like. Because when I see it written, I'm like. Maybe because I've never done inquiry before but like they helped to like bridge the gap almost. So I learned a lot from the reading. In class, our discussions were the most helpful. I would. yeah, the discussions were the most helpful. I would say that the building of the argument really maybe played a subordinate role to our discussions.

Leila – Post-Light Module Interview
In all these quotes, I identified an emphasis on being able to tell right from wrong and being sure about such a distinction. Moreover, I see learning as being recognized as derived from this ability.

5.2.4 What experiences result in learning?

Interestingly, not only reading is seen as an important experience for learning, instances in which seeing and/or doing occurred were indentified by PTs as particularly important experiences for their learning of science. All participants talked about the impact of seeing something happening in front of their eyes, and then, learning. The experience could involve seeing a phenomena taking place in an experiment or seeing a representation like a graph. Caroline’s comments illustrate the interconnections between learning, seeing and, again, having the feeling of being able to make a clear distinction between right and wrong.

I felt much more confident about our Light Module presentation than I did about our finch module presentation. And I think it's because I was worried that in our finch module, we didn't cover all the areas that we should. And I noticed that a lot of people did cover other areas, you know, that we didn't, you know, and vice versa. You know, we might have covered things other people didn't. And so, you know, I was always. I think in the back of my mind, I was worried, you know, okay, you know we think this because of this but, you know, did we look into this deep enough, could we have found more here or more there? Whereas, in the Light Module, I think it was just so clear and so evident for us. Like, you know, for example in our telescope, it was so easy to explain it because we could see it. Like you could see the light hit the mirror and go straight down through the lens. I mean it was like right there in front of us and we were, you know, able to, you know, really work off of that and go into our argument feeling really confident about it because we feel like we've pretty much, you know, covered all the factors that were important and essential.

Caroline – Post-Light Module Interview
Conrad, on the other hand recognizes that his initial ideas had an impact on how he looked at evidence, but seeing these notions portrayed in graphs convinced him of their accuracy.

C: Yeah. We. I don't think my position changed much, more than seeing that temperatures are increasing and they shouldn't be at this point. (…)

I: Okay, so let's, first, you were talking about the. Then you said something that your thinking changed about the temperature being changing a lot? (…) Can you explain?

C: Yeah. I guess I came in with minimal understanding like for global warming, that it was probably occurring, basically through like movies and stuff like that. And so I wasn't, like everyone else, convinced one way or the other. But I'm pretty sure having looked at all the evidence [inaudible] that it's definitely occurring. (…)

I: So, Chris, you came in thinking, okay, the temperatures are increasing.

C: I was thinking the temperatures are probably increasing, that there's probably something here.

I: And then what happened?

C: And then we saw graphs and like graph after graph after graph showing that temperatures are increasing. And then we started looking at it. I don't know that. I was convinced fairly quickly that temperatures are increasing because I was already almost convinced coming in.

Conrad – Post-Global Climate Change module Interview

Notably, reading and seeing come together in some of the participants’ comments. Leila, for instance, talked about the relationships of these two experiences:

L: Oh, okay. Good. Well, like they had. they had evidence but it wasn't conclusive enough. You know, like they were like, we know that black holes are this and so therefore, you know, a major, you know, explosion in space would cause this to happen. But at the same time I'm like, well, it's never really happened, how do you. like you cant just. like it was hard for me to just go on word alone. Like I wanted to see it. You know.

I: In this case, like when you.
L: And in this case, we could see it. You know. So that was good. Because we could make the graphs and we could see it right away. So it was like providing evidence real quick. So I liked that.

Leila – Post-Evolution Module Interview

Although Leila was not talking about reading, but about lectures she had in another course, she noted that “word alone” is not enough to promote understanding – she needed something else. In the Evolution Module, she found that something else in the graphs representing the frequency of traits in the population.

Caroline also talked explicitly about the relationship between words in a lecture or in a written text and seeing, as illustrated in the following quote:

I: And you mentioned that... I mean that's the second time you talked about [how seeing pictures] pictures was kind of important for you. Can you just elaborate a little bit more?
C: Just because I think I'm a real visual learner.
I: Ray diagrams.
C: Yeah, exactly. And I think, you know, not even as much for our reference but for, you know, whoever was, you know, gonna be assessing our portfolio and in our presentation, you know, I think it definitely helps to hear it and then see it because you're not just learning one way you're learning two ways. And, you know, I know personally if I read something, you know, even it could be as clear as can be and, you know, I could think I have the right picture of it and maybe I'm wrong, you know. So it's always better to have that double clarification so you know you're on the right track.

Caroline – Post-Light Module Interview

In this case, however, Caroline also talked about her concern with being right. This indicated to me that seeing and reading are learning experiences united by the fact that both have the potential to help to distinguish right and wrong. In the same trend, doing becomes another vehicle for this type of learning.

The comparisons Caroline made between the Light and the Evolution modules illustrate what a difference doing can make in learning:
C: I would say I learned more in the Light Module because you had to do more, you know, to get where you had to go kind of like because we were actually performing the experiments, gathering the evidence, putting it together, forming the argument. Whereas, in the finch module, we were kind of like given a lot of stuff already. You know, we had to formulate the questions and kind of organize the information and put it all together and, you know, look for patterns and whatnot, but it's like all the data, all the information was already given to us. You know, we weren't actually there like seeing the finches, seeing it happen, gathering evidence. So I think that extra little bit that we did was helpful. So, I think that's why I learned more.

Caroline – Post-Light Module Interview

However, when put into perspective, even the Evolution Module was initially identified as involving doing that goes beyond reading.

L: No, like... it helped to show like. A lot of the articles were like, students have... like students have to experiment on their own, like that helps the learning process. But like it totally did. Like if this module would have been set up with like just articles, like it wouldn't have been as beneficial as this because like we're actually going through and like doing stuff on our own. But umm... and like it did take a long time like to finally figure out like what we were... like what the end result was gonna be. But like it had... I think now it has more of an impact than I think reading other articles would be. You know, like if you would like pass out like the finch book, you know, or like a textbook of the finches, I don't... I think that would have been like not a helpful method for me to learn. Like this was helpful to learn about finches, but... And I can relate what I know now about like the evolution stuff to these things. So it was a good. See, I saw it more as an example. You know, like just like a teaching example. Like, relate this to other things now. So, that's what I saw. (my emphasis)

Leila – Post-Evolution Module Interview

The notion of learning by doing is also reflected in participants’ valorization of experiences in which they applied their knowledge to a practical problem. In these instances, in which you are able to apply your knowledge to something that works, doing became particularly significant for learning.
And when we were doing that experiment, I'm like, well, of course, I'm like it makes sense, the ray diagram, you know, whatever. But then when we got to our telescope deal and our microscope, like... like, seriously, we sat there for the week for the two classes and we were like, oh yeah, they're inverted, oh yeah. Like this is real life application to it. Like that. I guess I can apply more to. I can see myself applying more coming out of this module to like real life.

Leila – Post-Light Module Interview

5.3 Building relationships between aspects

5.3.1 Teaching as legitimization

Based on what was discussed in the section, How does one know learning is taking place? one could argue that Leila and Matt were simply asking teachers to tell them the answer to problems they encountered. To some extent I would agree, however, I believe this is an oversimplification of their ideas. We cannot ignore that one of the aspects of learning by seeing and doing which all participants referred to was that if the teacher simply tells them the answer one would not necessarily learn, it was important to see and to do in order to learn. When I combined the two aspects of perspectives on learning (i.e., need to do and to see with need to tell the answer), I constructed a richer picture of participants’ perspectives. Learning is seen, then, as learning as convincing/persuading. This notion appeared earlier in Matt’s comments about the purposes of argumentation when he noted that argument in Light was argument for teaching. As I further examined his experiences in learning, this concept of teaching and learning as convincing became even more noticeable to me. For instance, when he talked about one of his best teachers in high school:

M: Well, I had biology in high school in ninth grade and I thought my teacher did a really good job of it. I was telling somebody yesterday, I don't remember who it was, but... I don't know, I thought he started it off real well with like refuting... well, not refuting creationism, but just showing that evolution is not... like it's not like infringing upon your
religious beliefs in any way. This is, you know, like he said, I'm not here to change your mind, I'm not trying to tell you this is correct, you know, you don't have to believe it, but this is just scientific fact and this is what is widely becoming known as the truth. And umm... I thought he did a really good job because I just... well, if I was...I thought I was pretty close in a lot of these things. So if I can remember it after five years that much, I think he did a pretty good job.

I: And how did he teach you? Like do you remember? I know it's hard.
M: I know it was... I think it was like a lecture, like he did a... he would lecture on something and then I think he usually went back and did some kind of experiment or lab that would prove it. Like I remember when we picked beans out of a bag and like he had small beans and like kidney beans, which are larger, and he would just reach into a bag without looking and pull one out and it was of course easier to pull the large one out, so you would eventually see that the small beans were surviving. So, we did stuff like that. We might have done the dot lab... I'm not sure. But... umm... that's basically what he did was he just lectured. Then he would either... we would either do a lab or he would show us a video or a lab of some... or show us a lab on a video or something like that to support it.

Matt – Post-Evolution Module Interview

Matt’s positive learning experience illustrates how telling the answer is associated with seeing or doing to promote learning. Only one line of reasoning was pursued and the students had a secondary role in determining what was done in class, but, for Matt, exemplary learning of science was occurring.

Leila’s experiences in the Light Module also are helpful to think about how participants had more complex ideas than solely expecting to be told the truth:

I: Okay, let me try to rephrase that. You told me, okay, I learned the law of reflection. How do you know you know that? Why are you telling me that at a certain point you felt that you knew that? What made you believe that I know the law of reflection?
L: Oh man. Well, I'm sure this is the wrong answer, but you know J [the instructor for the Light Module] told us about the law of reflection, so I believed him. (...) He told us, I learned it. You know, like I remembered it because it was something that he said was important and that applied to the concept of light. So.
I: So, it made sense to you first?
L: Yeah, I was like, okay. Like, you know, I just was like, all right, J. You know, like that's basically, you know, that's what I... because he did a lot of the teaching in the beginning with the ray diagrams. Like it comes in here, how do you think it's gonna bounce off? And so when he showed us the diagram and was like, and this happens because when light enters the you know, and then it reflects off, that's why it happens. And so I was like, okay, that's why it happens. You know. So that's... you know.
I: No, sometimes, I mean teachers tell.
L: It wasn't like. Like I understood it. I understood the law of reflection before we went into the experiment, like no... like a single experiment to me in general didn't... didn't clarify anything. Like I always took what Joe said and I understood it and then when we did the experiment it was more like to see it, not to like prove any more. You know what I mean?
I: Kind of check?
L: Yeah, it was just like, okay, now we're gonna see it once more like how it's applied.
I: An illustration of what J said.
L: Yeah.
I: Okay.
L: Yeah, it was an illustration. Good.

Leila – Post-Light Module Interview

In this quote I see Leila initially stating that the instructor’s word was enough, but when he provided a more detailed description of the process through which she constructed knowledge a more complex picture emerged, a picture in which seeing and doing has a role in being convinced of the right and the wrong.

5.3.2 Parallels between learning perspectives and legitimization

In face of the relationship that I see emerging between learning as distinguishing right from wrong and learning as persuasion, other parallels assume a new significance. When I revisited the ideas defining the concept of learning as distinguishing right from wrong, striking parallels between this concept and the process of argument construction
as legitimization emerged. The very notion of learning right from wrong involves the belief of a clear and unambiguous distinction between what is right and what is wrong. Similarly, sending a clear message was a key element of the justification process. Furthermore, seeing and doing in learning involved adding a concrete or material component to the words of instructors/teachers/scientists in texts or in lectures. The reader should remember that concreteness was another important element in the process of legitimization – without something concrete, one’s argument is not accepted as valid.

These similarities reinforced my idea that learning was being seen as deriving from a very specific process of argumentation for persuasion, in which teachers provide enough legitimization to knowledge so it is accepted. I will further discuss this aspect in the Discussion Chapter.

5.4 An Uniform View of Learning? – Also for instructors and researcher?

The perspectives on learning that derived from my analysis of the interviews were relatively uniform. In the next chapter, I will further discuss this aspect, however, now I think it would be fundamental to briefly examine parallels between such a view and instructors’ and researcher’s perspectives on learning. Then, we could have some insights about interactions that might have occurred in the context of SCIED 410 and of the present study, and how they may have played a role in reinforcing the homogeneity that I observed.

First, I think it is important to notice that part of the structure of the course was indeed centered in the notion of learning right from wrong. When we asked PTs to record their previous ideas at the beginning of the course, and then examined their ideas again later in the course using a misconception paper we were establishing a clear distinction from right and wrong, and where one should be. Moreover, such pre-assessments were all centered around the learning of specific concepts, instead of processes or discipline-specific strategies. In this way, we were embracing the notion that learning could be captured in a few concepts and in limited pieces of information.
Another aspect of the course that reflects the centrality of the answer was the focus on the presentation and the journal for students’ assessment in accordance with a rubric.

The Light Module, following the conceptual change module, was the one that reflects best the view of learning centered in distinction from right and wrong, and in the learning of specific concepts (e.g., reflection, light travels in straight lines). The most illustrative aspect of this module is the fact that PTs were asked to make predictions and confirm/refute their predictions through experiments. (Notably, an aspect that PT’s particularly liked about the module and would like to use in their own teaching.) The design implies that there is a clear distinction between a good explanation and a bad explanation, and through concrete experience, people can learn such distinction.

Finally, it is important to examine the learning perspectives underlying the research design. When I say that I do not want to examine my own ideas/principles on the matter, but, instead, look at what I did in my research that portrays a similar perspective to that the one that I identified among my participants. A good example to illustrate this interplay between participant and researcher is the very question from which participants’ understandings of learning emerged. When I asked participants under which circumstances and how did they learn science in the course, first I tried to put into context what would be learning. My intention there was to help PTs think about their learning in a more concrete manner, in a way in which they could talk about specific experiences as examples. However, most of the time, when I started my conversations with participants about what they learned, I used the pre and post assessments designed for each module. Although that provided us (participants and myself) a good referential to see and talk about learning, it brought into the research a particular notion of learning. As we discussed before, this notion was centered in the learning of specific concepts and whether there was a movement from inaccurate to correct conceptions. One cannot deny that this approach certainly limited the possibilities for emergence of other notions of learning from participants, despite the occurrence of such learning.
1 Introduction

Since the inception of this research study, my interest has been in the relationship between argumentation and learning. My initial research question focused on argumentation and learning; data collection was designed and conducted to assess learning in the context of argumentation, and coding was conducted considering learning and argumentation as important aspects. As data collection and analysis progressed, I was confronted with issues that seemed to be disastrous to my research. There was a strong indication that participants did not perceive that they were learning science through their experiences with argument construction in SCIED 410. Did that mean that the study would end up not being about learning but about not learning, or impediments for learning? Would I have to abandon this central concept of learning? Fortunately, as the analysis continued and the complexities of learning were elaborated, this referent again acquired an interpretative and explanatory power.

In this chapter, it is through the lens of learning that I discuss PTs’ experiences with situated argumentation. It represents a tentative attempt to explore how notions of learning are embedded in and interrelated to another series of contexts and aspects of argumentation. I acknowledge that I could have approached the discussion in different ways, but I was guided by this particular (and, in fact, already considerably broad) interest. For instance, I could have focused on participants’ understandings of the nature of science to discuss (and think about) the results I constructed. However, instead of using understandings about science as my lens, these understandings are seen through the lens of learning. The questions that emerged were no longer How understandings about
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science are reflected in certain experiences? but became What these understandings tell me about learning? and How these understandings may be impacting learning?:

Considering my emphasis on learning, I believe it is pertinent to briefly revisit my ideas about the significance of the relationship between learning and argumentation. Thus, I will begin the chapter with a discussion of this aspect. Then, I will discuss the first research question by presenting my reading of participants’ perceptions of the process of argumentation, considering perspectives on learning – that is, embedded in the understandings constructed through the investigation of the second research question.

2 A Perspective of Argumentation and Learning Emerging from this Study

Like any other notion, argumentation can have different meanings for different people and in different contexts. In the process of doing research on argumentation, researchers typically narrow the meaning of argumentation in an effort to define the object of one’s research. This appears to be a “normal” and reasonable approach to take. I did that at the beginning of my dissertation. However, many researchers narrow their definitions of argumentation and then, in a second moment, propose that these narrow definitions could be definitions of what argumentation is in a general (or universal?) sense. How can that happen? I argue that this is happening mainly because, in this process of generalization, people start to ignore the context in which the narrow definition of argumentation was conceived. In other words, argumentation is decontextualized. My study was about situated argumentation and, because of that, I repeatedly made an effort to contextualize argumentation. Going in the opposite direction of other researchers in science education, I tried to put my general ideas about argumentation into a specific context and approach the interactions that occurred in this context. My focus, then, became the participants’ perspectives of their experiences with argumentation, instead of whether or not my participants were able to comply to some basic requirements that would make their arguments good arguments (for an example of
this type of research see Zohar & Nemet, 2002 or our prior work in Zembal-Saul, Munford, Crawford, Friedrichsen, & Land, 2001). In this process of shifting foci and contextualizing argumentation, what happens is that instead of a unified view of argumentation, multiple argumentations come into existence.

This has serious implications for the relationship between learning and argumentation. In a context of a single and unifying view of argumentation, to learn is to be able to engage in this argumentation and to construct scientific knowledge through this type of argumentation. However, learning acquires a more complex (and diverse) form in the context of multiple understandings of argumentation and multiple interactions with argumentation. What once was learning may not be learning anymore. What once promoted learning may not be promoting learning anymore. One could never completely explore the complexities of this new context. My intention in the following discussion is to share the insights that I have developed through my experience in a specific context.

3 Processes of Argument Construction and Learning

3.1 Legitimization

Legitimization was identified as the most prevalent process of argument construction in SCIED 410. A first impression about the legitimation process could be that it does not promote meaningful learning, considering what it represented (i.e., a commitment with finding an acceptable answer). The legitimation process is only about giving what you are asked for and not constructing knowledge. However, it is worth asking what type of learning would be promoted or would be occurring through legitimation.

3.1.1 Learning about the practices and norms of science

Various authors have argued that one of the most significant uses of argumentation in science teaching is that science students have an opportunity to engage
in scientific practices. In this context the *content of science*, is not seen as solely scientific concepts but also practices and ways of knowing through which this knowledge is generated (see for instance, Brickhouse, Dagher, Shipman, & Letts IV, 2000; Driver, Leach, Millar, & Scott, 1996; Driver, Newton, & Osborne, 2000; Helms & Carlone, 1999; Lederman, 1992; Matthews, 1998; Turner & Sullenger, 1999). Argument construction as legitimization was the most prevalent process in participants’ experiences engaging in situated argumentation. Despite its limitations, legitimization focuses on *norms* for determining what is acceptable knowledge, an important aspect of the nature of science. In SCIED 410, PTs learned about norms and were able to construct arguments following these norms, and became conscious of the existence and value of these norms. Thus, in the context of a science course, legitimization has the potential to support *learning about science* in aspects such as what counts as evidence and how you justify an explanation. What would be the significance of the new knowledge that is constructed through legitimization? Driver et al. (1996) presented a series of arguments for the inclusion of the nature of science as content in school science: a utilitarian argument, a democratic argument, a cultural argument, a moral argument, and a science learning argument. I will examine which of these arguments stand as they relate to the specific case of legitimization.

First, in accordance with a utilitarian argument, “an understanding of the nature of science is necessary if people are to make sense of the science and manage the technological objects and processes they encounter in everyday life” (p. 16). Driver et al. refer to both material products of science (e.g., tools) and intellectual products (articles in magazines and textbooks). In my view, legitimization could support participants in evaluating the intellectual products of science, examining whether or not they would be considered *valid scientific knowledge*, considering norms of science (e.g., explanations being supported with evidence). Second, in accordance with a democratic argument, “an understanding of the nature of science is necessary if people are to make sense of socio-scientific issues and participate in the decision-making process” (p. 18). The knowledge about norms of science, reflected in legitimization, can empower participants in
constructing explanations or arguments for a certain position so it can be considered an appropriate argument considering the criteria of science.

Based on the results of the present study, I do not believe that legitimization contributes to understandings of the nature of science that would support three of Driver and colleagues’ (1996) arguments. Legitimization would not help students “to appreciate science as a major element of contemporary culture” (p. 19) (the cultural argument) or to “embody moral commitments which are of general value” (p. 19). By understanding and being able to use scientific norms, participants did not necessarily recognize those ways of thinking as the most powerful ones. Importantly, they were able to question them. The lesson learned here was that the power of science in our society does not lay solely in its efficiency, but also involves the exclusion of other ways of knowing. For those who value these alternative ways, simply to learn about science does not result in embracing the “aims and aspirations of scientific enterprise” (p. 19). I will discuss this issue in more detail later in this chapter. Moreover, legitimization is not supporting PTs’ “successful learning of science content” (science learning argument) (p. 20). I created the concept of legitimization based on a disconnection between complying with norms and learning scientific concepts. Thus, it is not surprising that this type of argument is not supported by legitimization.

Now, that I explained my view on the significance of knowledge about the norms that validate knowledge, two questions need to be addressed. First, what was legitimization situated in SCIED 410? And, second, did participants recognize learning about science norms and practices through legitimization? I will address these questions in the next sections.

### 3.1.2 Examining the Notions underlying Participants’ Legitimization

What were the norms that I identified as being present in legitimization in the particular context of this study? Interestingly, relatively similar understandings of what occurs in legitimization were identified among participants. Although these understandings did not always reflect what instructors saw as being norms of scientific
argumentation, they, at least, reflect PT’s understandings of what was seen as scientific argumentation in SCI ED 410.

Concreteness

One important concern that has been voiced frequently in the science education literature is that science knowledge at school is presented in a way that disregards its empirical basis. Chinn (1998), for instance, argues that school science has simply ignored the existence of a concrete world because of the absence of the use of empirical evidence to support scientific concepts discussed in class. In this context, Chinn notes, it is the teachers’ authority that determines what scientific knowledge is and why it is valid. Interestingly, the literature on argumentation parallels this concern. Subjects engaging in argumentation tend not to use evidence to support their explanations, do not make a distinction between evidence and explanation, and do not explore counter-arguments or alternative explanations (Brickhouse et al., 2000; Driver, Guesne, & Tinberghien, 1985; Kuhn, 1991, 1992).

In the present study, participants viewed providing evidence to support explanations as one of the most important aspects for validation of one’s argument. They not only included evidence in their argument but also talked about how essential it was to make a “good” argument. This indicates that they were not only able to construct evidence-based arguments, but also recognized this as an important norm for evaluating the quality of an argument in the context of SCI ED 410. In face of the concerns described above, this represents an important accomplishment, indicating the potential of argumentation for science education. Although other studies of argumentation in the science classroom reported similar results with regard to students’ use of evidence (Jimenez, Rodriguez, & Duschl, 2000; Kelly, Druker, & Chen, 1998; Yerrick, 2000; Zohar & Nemet, 2002), these studies provide little insight into participants’ perceptions of the use of evidence, since analyses was based on artifacts produced by participants and/or classroom discussions. Thus, the present study provides additional support to the
notion that argumentation practices in the classroom promote the use of empirical evidence in the construction of scientific arguments.

However, it is fundamental to look closer at participants’ uses of evidence and its significance both to better understand the process involved in argument construction and to re-examine goals for science education such as those proposed by Chinn (1998). In that sense, the notion of concreteness is much richer than the restricted focus on evidence. The issue becomes not whether they provide evidence, but under which conditions and with what purposes.

Although participants were using evidence, there are a series of issues involved in the ways of doing so, and in the understandings underlying their actions. First, in various instances, PTs did not examine multiple explanations; they used evidence only to support explanation. As Kuhn (1991) noted, in this conditions, evidence use acquires a new significance. Since it is not used in the context of genuine consideration of multiple explanations and counter-arguments, the distinction between evidence and explanation cannot be considered as separate. This issue will be further explored in the following sub-section, emphasizing the interconnectedness between the concept of concreteness and that of conveying a clear message. For now, I would like to call attention to some clues that indicated that the use of evidence *per se* was not an indication of an understanding of the role of evidence as the science education community has conceived it.

Second, we should remember that underlying the notion of concreteness was the idea that having something physical/material to support your claims was required for acceptance of your ideas. In my interpretation, the notion of evidence as proving the truth is embedded in the concept of concreteness. Driver et al., (1996) discusses the importance of understanding that scientific theories (and scientific explanations) are always undetermined by data (p. 43), that is, data never completely define the explanatory frameworks that are constructed. Informed by their work, I believe that the participants’ strong focus on concreteness could indicate that they do not understand that data will not tell everything, and that there will always be inferences involved in the process. The use of inference was illustrated in their experiences in the Light module.
To see an inverted image of the candle flame on the screen was taken as a proof that light travels in straight light. If participants’ use of evidence was influenced by this understanding of the role of evidence, we should not be so optimistic about the fact that they supported all their explanations with evidence. In this case, understandings of evidence as reality that underlie their appropriate behavior are in direct conflict with what we as science educators want to convey. Scientific knowledge and practices should be seen as a process of construction of knowledge based on lived experiences, and unfortunately, they are being perceived as a process of fact gathering. This has further implications in the context of science education if one considers the subject matter of science as being constituted of both “demonstrable knowledge” and “arbitrary knowledge” as proposed by White (1994). For instance, an example of an arbitrary proposition is the statement that electric current flows from the positive terminal of a cell (p. 260), although it is impossible to have concrete evidence to show this. In other words, if the notion of data tells all is taken seriously, much of the scientific knowledge would not be considered as valid knowledge.

Another possible interpretation of the focus on concreteness could be related to participants’ understandings of the aspect of science they are engaging in when they construct arguments. Again, I argue that it is fundamental to remember that PTs did not perceive legitimization as an experience of learning – or as an experience that lead them to construct new scientific knowledge. Thus, they did not engage in the process of legitimization as they would in a process that would lead to learning. What I inferred was that participants saw legitimization, not as a process occurring in the context of discovery, but, instead, in the context of justification of knowledge. Although some authors had criticized the separation of these two contexts (e.g., Hess, 1997), the point here is that in participants’ perceptions, a clear separation may exist. If legitimization is placed in the context of justification, the use of evidence is similar to the use of evidence in a courtroom. The purpose is to have others accept one’s explanation, and not to represent the complexities of one’s understandings about the topic. Note that through this process participants are learning about norms for acceptance of a certain type of
knowledge and not for construction of knowledge, which are quite different (Latour, 1987; Roth & McGinn, 1998). Evidence in this context does not have the same meaning as it would in the context of discovery, and does not necessarily reflect participants’ understandings of “reality” in other contexts, as I argued before. Moreover, legitimization in SCIED 410 could not reflect participants’ understandings of evidence in other contexts of justification.

The notion of contextual dependency of legitimization is particularly interesting in this respect. The story of Matt, for instance, illustrates my point (see page 214-215, chapter 7). In many instances, Matt repeatedly emphasized that one must provide evidence. Suddenly, he did not provide evidence at all. In this new context, evidence was not important anymore. Why? I argue that it is because evidence does not have a value on its own, but its significance would depend on the context in which one uses it.

As a final comment, I would like to call the reader’s attention to the fact that evidence occurs not only as an important element of the concreteness concept, but also in all other aspects of legitimization. Evidence has an important role in articulating an explanation, sending a clear message, and in context-dependent aspects. This predominance of evidence in the process of legitimization could be related to what Kuhn (1991) described as an absolutist epistemological theory that is centered on facts. From this perspective, for example, certainty of the accurateness of an explanation would be based solely on factual observations, and divergences of point are (or should be) resolved based on facts. But then, why did not the same kind of epistemological principles occur when participants engaged in other processes? Maybe the epistemological theory does not lay in the individuals, but in the interactions that occur in a certain context – in this case, the context of the process of legitimization in a science course. That leads me to wonder if by emphasizing the use of evidence to support ideas, we, as instructors, were taking the risk of substituting teachers’ authority for a hegemony of evidence in the norms of science. A serious consequence of such a hegemony of evidence would be, again, an inappropriate portrayal of the scientific endeavor (and knowledge).
Conveying a clear message

As PTs constructed their arguments through legitimization, another major focus was to convey a clear message. They would ignore conflicts, choose evidence that was unambiguous, and not consider alternative hypotheses. Interestingly, this type of concern is not new to either the context of argumentation, of science, or of school.

Dewey critiqued two notions that had been central to the Western thought (Dahlin, 2001), both oriented by a commitment with achieving certainty (Boisvert, 1998). Although he was not criticizing these ideas in the context of science, but in the context of philosophy, they are very useful to understand the concept of conveying a clear message and its possible origins. The first notion, what Dewey called Plotinian temptation which I will call oneness (a term used by Dahlin, 2001), represents the search for a single, universal and irrefutable idea that would explain a phenomenon. Dewey saw this reduction of the diversity and possibilities of ideas as very problematic (Boisvert, 1998; Dahlin, 2001; Dewey, 1958). The second one, called Galilean purification would represent more a means to achieving the certitude of oneness, in my interpretation. It involves a process of (over) simplification of factors used in the explanation of a phenomenon in a way that an idealized situation is created – one in which all factors can be explained and predicted (Boisvert, 1998; Dahlin, 2001). Dahlin (2001) uses the following example to illustrate Galilean purification: “Galileo’s law of free falling bodies exemplifies the Galilean purification, which ignores such factors as the friction of the air and other accidental circumstances” (p. 455). Dewey warns philosophers that to fall into such temptation and to practice purification would result in the elimination of important aspects of lived experience, which are eliminated to avoid compromising certainty. The similarities between the two notions and elements of the concept of conveying a clear message are striking.

1 Interestingly, Dewey accepted “Galilean purification in the helm of science but not in philosophy. I do not intend to discuss his reasoning, but it is puzzling, to say the least, that in science it is not a problem to ignore such an important part of phenomena because of the sciences’ purpose. Would the same hold for science education?
In the context of schooling, the same ideas related to the goal of certainty are present. Brown, Collins, & Duiguid (1989), for example, discuss the work of Jean Lave with learning outside school and the differences that emerged from comparisons. They pointed out that at school, students work with well-defined problems, are expected to reason with laws and “produce fixed meaning and immutable concepts” (p. 35, my emphasis). In other words, students’ experiences are centered in purification of process (laws) and problems (well-defined), resulting in “clear messages” (immutable concepts).

Finally, research on argumentation indicates that subjects tend to explore a single explanation for problems, extensively supporting it with confirmatory evidences. Kuhn (1991, 1993) argues that if alternative explanations are not considered, people are not engaging in argumentation. Argumentation requires recognizing a universe of possibilities. In the present study, I noticed that when participants experienced argument construction as legitimization, they focused solely on one explanation. Brickhouse et al. (2000) argue that one of the impediments for exploring multiple explanations is that, in some cases, students were never exposed to other explanations. They drew such a proposition from a study in which students had to construct explanations for why things fall, the origin of the universe, and animals’ evolution. Students were able to reflect on multiple explanations for all the topics, except the first one. The authors note that inside and outside of school, people tend to be naturally exposed to alternative explanations about the origin of the universe and animals’ evolution, but usually gravity is presented as the only possible explanation for why things fall. Thus, this would become the one explanation for why things fall.

This notion that exposure to alternative hypothesis is key to the process of generating alternatives is coherent with some findings of this study. In the Light module, PTs were exposed to a single explanation in the classroom and they focused on it in the process of argument construction. In this case, legitimization was stronger than in any other module. On the other hand, in the Evolution Module, when exposed to possible alternatives, participants did explore multiple explanations and tried to support them with evidence (though not always genuinely). This process sometimes involved experiences
other than legitimization. Nevertheless, this *theory of exposure* does not stand in face of Conrad’s choice to *not* address alternative theories to which he had been exposed (see p. 197-198, Chapter 7) or to move from legitimization to guidance within the same module (see p. 221, Chapter 7). *Why? What was happening there?* That brings me back to the idea of argumentation as situated in a specific context of interactions. We cannot understand the processes of argument construction without considering how participants made sense of the context and what their motivations were considering such understandings. I will discuss this in more detail later, but, for now, I wanted to emphasize the limitations of explanations that consider the context as external to participants.

Furthermore, I believe we should be cautious not to conclude that those who pursue alternative explanations are not driven by the notion of “oneness.” As we saw in the process of legitimization, to pursue multiple explanations may be seen as a way to find or prove the best idea. As illustrated by Leila and Matt’s experiences in the Evolution Module, multiple explanations can be pursued with the purpose of discarding them. Moreover, people can explore multiple explanations, but, in the end, they fail to acknowledge the existence of these open possibilities since they do not have the same explanatory power as *one* of the explanations. I am not arguing here that people should avoid taking a position and choosing one explanation; my point refers to the status of the alternative explanations that become *invisible* at the end of the process. In my opinion, this merely implies a different way to achieve “oneness.”

**Out of context: how personal experiences are not part of legitimization**

An important aspect that emerged in the development of the categories constituting legitimization was how this process was context sensitive. In this category, a particular sub-category illustrates what belongs to the process of argument construction situated in SCIED 410, and what does not – how only evidence coming from the specific course counts as evidence. I would like to discuss this particular example in light of notions of authentic science. Where is the connection? So far, we noted that legitimization could be seen as a set of norms and practices that would reflect what
makes an argument valid or acceptable. In this study, arguments were constructed to respond to scientific problems, thus legitimization reflects what an acceptable response to a scientific problem should be like in this particular course. Depending on what is included and what needs to be excluded from those responses, I made inferences about what is the science of SCIED 410. Could I call SCIED 410 science, authentic science? To what extent? Since evidence has been an important element across all categories of legitimization, this example appeared to be particularly appropriate to provide insight into the issue.

Authentic science has acquired multiple meanings for science educators (Edelson, 1998; Martin, Kass, & Brouwer, 1990). Two views have prevailed in the educational literature (Putnam & Borko, 1997). On one hand, some authors have argued that authentic activities should reflect practices of the academic culture that generated the knowledge, in the case of science, the culture of the scientific community (Brown et al., 1989). On the other hand, for other authors an authentic activity should promote the development of thinking that would help learners in solving problems in their everyday lives (Brown et al., 1993 [as cited in Putnam & Borko, 1997]). Some authors do not see these two views as necessarily opposing views, proposing that one can, in fact, be used to facilitate and support the other (Cunningham & Helms, 1998; Roth & Bowen, 1999; Roth & McGinn, 1998). However, others have expressed their concern that “the acculturation of students into an academic environment” could destroy “their zest for learning,” impair “their respect for an understanding of their own cultural traditions,” and impose values strange to their society (Palincsar, 1989, p. 7).

In the context of the present study, such a concern is justified. PTs were able to identify parallels between what they did in SCIED 410 and what scientists do. However, as the example of use of evidence indicates, PTs tended not to connect their experiences in the classroom with experiences from outside the school (or outside the course). This lack of connection has at least two serious implications. First, it implies that limited learning of science is occurring through legitimization in SCIED 410. There is extensive evidence in the literature that “the development of scientific concepts both depends and
builds upon an already existing set of everyday concepts” (Panofsky, John-Steiner, & Blackwell, 1990), p. 252). In the particular case of argumentation in school science, these connections have been considered essential (Jimenez et al., 2000; Zohar & Nemet, 2002). For example, their absence could influence learners’ ability to generate multiple alternative explanations (Brickhouse et al., 2000).

Second, the exclusion of everyday life from school science can also go beyond *material* elements of learners’ worlds. When engaging in science and argumentation in the classroom, selves as situated in a culture and in a society that may be alienated in the process. Some authors have argued that scientific knowledge and ways of knowing have excluded women, people of color, and underprivileged groups by privileging certain forms of knowing (Barr & Birke, 1998; Barton, 1998; Croissant & Restivo, 1995; Restivo & Loughlin, 2000). In this study, I believe we have a good example of such a process of exclusion in Leila’s experiences. I am not arguing that this process was initiated in the specific context of the course, but we cannot leave it unexamined. The similarities between her perceptions of science articulated through her experiences in SCIED 410, and the perceptions of working class women in Barr & Birke’s (1998) research are striking. In Barr & Birke’s study, women talk about a feeling of estrangement in relation to science (e.g., “science is not me”), and how it has nothing to do with the world around them. Moreover, for several of them, “science means boredom, a plodding approach to solving problems” (p. 64). The memories of science learning also are quite similar—always having to find the right answer.

This conflict with science becomes even more problematic in the context of experiences in constructing arguments because there may be a sense of losing one’s voice as one has to use a specific type of genre to communicate (Cazden, 1993). In the particular case of women, argumentation can be experienced as a distanced and confrontational mode of communication (Schweickart, 1996). As Schweickart (1996) states, “Whereas a separate knowing requires the depersonalization both of self and of others, the connected knowing preferred by many women is predicated on a respect for knowledge that is based on personal experience, and on imaginative attachment to the
other” (p. 312). The absence of this type of knowledge in the classroom can easily exclude women from engaging in science. As educators, we may not be directly responsible for such an exclusion, but still we have to acknowledge the problem and search for more empowering science education. In Barr and Birke’s words,

An empowering science education for them [women] would have to make connections between lived experience and structures and processes not available within that everyday experience. In defining science and argumentative modes as “not me”, in valuing personal and connected ways of knowing over the kind of knowledge they see science as representing, they may deny their own capacity for knowledge that goes beyond the familiar. (p. 47)

3.1.3 Absence of Science Subject Matter: The Gap between Practices and Knowledge

An important observation deriving from this study is the fact that in SCIED 410, the process of legitimization did not include the use of discipline-specific knowledge and strategies. The emphasis was in clearness and concreteness throughout the course. That was surprising to me in the Evolution module for two reasons. First, instruction, curriculum and software were designed to emphasize this aspect. Second, because the analysis of participants’ arguments indicated that they were using discipline-specific criteria to construct explanations. In my interpretation, these results indicate that participants experience science knowledge and scientific practices (in particular scientific norms) as disconnected, even though their arguments would tell the opposite story.

Researchers have been enthusiastic about the presence of discipline-specific knowledge in participants’ arguments (see for instance, Sandoval & Reiser, 1997a; Zembal-Saul et al., 2001; Zohar & Nemet, 2002), but this is not enough to capture the complexities of the relationship between scientific knowledge and scientific practices. Evidence from this study indicates that participants, despite their actions, were still seeing knowledge and practices as separate. More importantly, these people (PTs in the present study) were able to function as science students while holding these conceptions. Usually, scientific knowledge is presented outside the context of the practices through
which it was constructed (Brown et al., 1989; Driver et al., 1996). This was at the heart of Joseph Schwab’s critique of science education in the 1960s and his proposal to bring scientific enquiry into the classroom (Bybee, 2000; Duschl, 1994). Since then, many have joined Schwab, both in his critique and in his proposal, but it seems that little has changed. My concern is mainly that to promote integration between knowledge and practices it is not enough to engage in scientific inquiry and make explicit the workings of these practices in the classroom. Authors like Matthews (1998) proposed that besides understanding and engaging in specific practices of science, participants should situate these practices in a cultural, social and historical context. I believe that part of this process of situating the scientific endeavor in a broader context should be accompanied by a more critical view of science as a mode of inquiry (see for instance, Restivo & Bauchspies, 1997; Restivo & Loughlin, 2000). Science educators have embraced the idea of argumentation as important for science learning, recognizing that it is through the collective and dialogical examination and comparison of multiple explanations that people can learn (Driver et al., 2000; Kuhn, 1991, 1992, 1993; Pontecorvo, 1987). Nevertheless, there is little of that when it comes to addressing ways of thinking about the natural world. In the present course, it was through the comparison of different modules that participants had most of their insights into their understandings about argumentation and learning. In my view, the relationship between practices and knowledge can only be understood when contrasted to other ways of knowing (or practices) and the knowledge that is produced. In other words, people have to live the differences to understand relationships.

### 3.1.4 Problem: Are these really the Practices of Science?

At various points in my discussion of the notions present in legitimization in SCIED 410, I talked about both norms of science and the situation of being at school. The science course is a place where the two meet. In this complex context, where school, science and learning are put together, is legitimization seen as part of science, as part of learning science, as part of schooling, as part of science education? We initially assumed that, from an instructors’ perspective, the value of legitimization would be to promote
learning about science. Then, I contrasted these notions to those that are embraced by scholars in science education. However, this does not mean that participants experienced legitimization as an aspect of science – that is, maybe when they engaged in legitimization, they did not perceive these experiences as experiences of engaging in scientists’ practices. The complexities that emerged in each of the aspects discussed so far may derive from these different perceptions. In fact, my interpretation of their experiences led me to believe that the significance of this experience is quite diverse and multifaceted. Notably, participants going to the same class and engaging in the same activities did not have the same experiences.

The specific case of the significance of legitimization for various participants is a good example to illustrate how individuals’ experiences can be so different. In my interpretation, for Leila to engage in legitimization was to do what scientists do, that is, she was playing the scientist. In other words, it was perceived as an experience in science. For Matt, it was, in part, an experience in science, but it also involved general reasoning patterns. Thus, legitimization was not only an experience in science, but mainly an experience in what Matt considered to be rational thinking. Caroline recognized parallels between science and her experiences in the course, but her account of them focused on how she was learning. Conrad represented a particularly interesting case because he apparently had very contradictory behaviors in class, when engaging in legitimization, and outside class. For instance, he, like all the participants, held the notion that for an argument to be valid, it should convey a clear message. However, Conrad intentionally ignored in class a conceptual conflict that he held (I didn’t want to open that can) (see p. 198, Chapter 7). That is, he intentionally and consciously aligned with the clear message criteria. Later, in the interviews, he was willing to discuss this issue. In other words, as he moved from one context to another, legitimization was not important anymore, or at least did not have the same power and/or significance. How could we explain this?

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2 In fact, we scheduled a meeting with the instructor to further discuss the issue.
In my interpretation, legitimization takes place in a complex context in which different views about learning, schooling and science interact. The nature of these factors and their relationships need to be further explored, but Conrad’s story illustrates how he was keeping the influence of different factors separated in different contexts. In the classroom, the primary focus was typically to accomplish the task and get things going was the most important – thus, legitimization as portrayed earlier, became his focus. In the context of the interviews, Conrad’s interest for science and for learning could be pursued; thus, he engaged in other forms of knowledge construction. In contrast, such a distinction, and the conflict underlying it, did not occur for Leila and Matt. For Leila, legitimization was about science; thus, whenever she had to think scientifically she would engage (or try to) in legitimization. For Matt, to follow legitimization meant, in part, to be rational; thus, whenever he wanted to be (or appear) rational he valued and attempted to engage in at least some aspects of legitimization.

Such a complexity and my way of approaching it, call attention to the types of interactions that may be occurring in the context of legitimization. These interactions could help us to understand why legitimization is such a prevalent process of argument construction. I will discuss interactions in relation to three aspects that I believe can provide some insights to the issue: (a) Is the argument construction process about science practices or general reasoning patterns? (b) Is the argument process construction related to the practices of schooling? and (c) Is the argument process construction related to conceptions of learning that emerged in the course?. My intention is not to exhaust these questions, but solely to pose them and initiate their exploration.

**Discipline-specific practices or General reasoning patterns**

It is interesting to see how Matt and Leila had such different perceptions of the process of legitimization. For Leila, the various aspects of legitimization reflected the practices of science, whereas for Matt the same process involved some basic and general processes of thinking (e.g., supporting claims with evidence and justification). One should note that, as instructors, we did not have the intention to promote either of these
views (see Chapter 3). Leila believed in a unity of science that has been long criticized (Brickhouse et al., 2000; Driver et al., 1996; Driver et al., 2000; Hess, 1997; Rudolph & Stewart, 1998), whereas Matt could not recognize the particularities among different fields of science as well as between those and other disciplines (e.g., history). (See Toulmin, Rieke, & Janik, (1979), for instance, for a discussion of argumentation in different fields).

Interestingly, these different perceptions (between PTs and between PTs and instructors) reflect a still current debate among scholars: are the processes reflected in thinking discipline-specific or not? In particular, is argumentation a process that can be described as a general thinking process or is it more like a discipline-specific one? Toulmin, as one of the most prominent scholars in the contemporary field of argumentation, would argue that yes, there are discipline-specific aspects but there are overarching structures that can be applied across all fields (Toulmin et al., 1979).

As authors brought argumentation into the context of learning, different authors argued for an emphasis on different aspects. Some authors have worked within a framework that appears to be quite similar to that of Toulmin. Zohar & Nemet (2002) argued that “general and specialized knowledge function in strong partnership” and that “general thinking patterns are adjusted to the knowledge structures of specific domains” (p. 37). However, she does not describe in detail which would be the general or the domain-specific aspects. On the other hand, Kuhn emphasized the general aspect of thinking. She saw scientific thinking as a more general process that would involve the analysis of evidence, the justification of explanations, the examination of multiple hypotheses, and the consideration of counter-arguments (Kuhn, 1991, 1992, 1993). Kuhn’s focus derives from her concern with bridging everyday thinking with scientific thinking. Thus, she recommends that this general thinking process become part of science education so it can promote a way of thinking, instead of the diffusion of facts. Critics of Kuhn’s work argue that in her research she did not address problems that were “embedded in conceptual content of science” (Brickhouse et al., 2000, p. 12, see also Driver et al., 2000). Consequently, Kuhn never had a grasp of the significance of these
concepts. These authors’ critiques derive from the observation that students’ thinking related to, for example, coordination of evidence and theory, can greatly vary from one field to another (Driver et al., 2000). Following this same line, some authors have discussed the importance of domain-specific knowledge when one is confronted with a problem in science. Domain-specific knowledge of concepts and strategies can support learners in discriminating between more or less plausible hypotheses, influence the choice of variables, shift the focus of attention to certain features and influence the types of observations one makes (Tabak, 1999). A pedagogy centered in this notion would have the potential to promote a better understanding of the concepts and practices of science than one that ignores domain-specific knowledge (Sandoval & Reiser, 1997a, 1997b; Tabak & Reiser, 1997; Tabak, Smith, Sandoval, & Reiser, 1996).

In light of this discussion, the contradictions among participants in this study gain another significance. In my interpretation, discipline-specific knowledge was not valued by our students. To some extent, that is not surprising, since only in the Evolution module was the investigation and argument construction centered in discipline-specific concepts. In the other two modules, and throughout the course, there was an emphasis on the general aspects recognized as the most important by Kuhn and Toulmin. In the future, it would be important to emphasize more aspects of the domain-specific knowledge as reflected in the structure of the argument and process of argument construction to challenge views of uniformity in thinking across scientific disciplines, and, if possible, across different academic disciplines.

Legitimization as a Process of Schooling?

I perceived Conrad’s experience in the Light Module as an example of how someone could have completely different responses to the same problem in different contexts. In her work with high school students, Pope (2001) talks about how students survive in school by behaving like chameleons. The same image of chameleons comes to my mind when I think about Conrad adapting to different contexts – contexts that he was able to distinguish. Like Conrad, students in Pope’s research talked about the difference
between “learning” and “playing the game” (see page 190, Chapter 6). However, they would add comments on how school was turning them into “high school machines” (p. 154). In this process, students do not gain deep understandings of the subject matter, and they do not engage with genuine interest in the activities, they were basically focusing on accomplishing the task to get a good grade (Pope, 2001). Interestingly, some students in Pope’s study argued that it would be impossible to survive in the system if you did not play the school game. In my interpretation, Conrad’s contradictory behavior in relation to his conceptual conflicts in the Light module reflected perceptions of the context of SCIED 410 (or college as a whole) that were similar to those of Pope’s participants.

In fact, this type of perception is not a rare one in the context of schooling, and is not exclusive to students. Bloome, Puro, & Theodorou (1989) coined the term “procedural display” to refer to situations in which teachers and students engage in what Pope called “doing school”:

Teachers and students may enact a lesson, say what “needs” to be said to each other, move through and complete the lesson, without necessarily knowing or engaging academic content; yet, they are constructing an event called a lesson that has cultural significance. (p. 272)

This concept was used by Jimenez et al., (2000) to understand high school students’ argumentation in a biology class. These authors used discourse analysis to identify and distinguish instances of “doing science” versus those of “doing school” (or “doing the lesson”). “Doing school” involved instances in which the focus was on accomplishing the task, and interactions between students were organized around the teacher’s expectations. For example, in Jimenez et al. (2000) study, students talked about how the course was about genetics; thus, the problem should be solved using genetics. “Doing science” involved “exchanges when students are evaluating knowledge claims, discussing with each other, offering justifications for the different hypotheses, and trying to support them with analogies and metaphors” (p. 771). Conrad’s example offers new insights into what it means to “do school”. Although he engaged in behaviors like justifying his beliefs, he was not actually engaged in “doing science”. Notably, his behavior of “doing
science” involved revealing his uncertainty about certain phenomenon, the conflicts and confusions that emerged in face of the “scientific problem,” and the recognition of limitations in his knowledge that needed to be addressed.

Unfortunately, “doing science” did not occur in the classroom and Conrad, his colleagues and instructors could not benefit from that. There, he needed to keep things going in their usual and programmed rhythm. It is important to note that the search for success at school that led to a chameleon behavior does not imply that students lost their pleasure for learning. The participants in Pope’s study were sometimes “extremely focused on their work, passionately committed to doing it the best possible way, and willing to toil long hours until satisfied with the results”... reflecting a “sense of passion, of intrinsic motivation to complete a task well, regardless of grades.” I perceived the same passion, commitment and dedication in Conrad when we had opportunities to discuss science. As instructors, we should be seriously concerned with the fact that legitimization came to represent a schooling process at odds with intellectual development.

Legitimization and Learning

After repeatedly stating that legitimization was not recognized by participants as involving learning, it may appear contradictory to question the relationship between participants’ experiences in this process and their understandings about learning. However, I argue that there are interesting parallels between the uses of evidence in legitimization and the role of evidence in learning, as well as the need for a clear message to be conveyed. First, as I noted in the previous chapter, some participants’ experiences in the course were interpreted as indicating that they held conceptions of teaching and learning that were centered in legitimization. To state that what participants considered to be good teaching was defined as providing a coherent and linear argument that lead to an easy decision about what is right and wrong, is not a new contribution to literature. For decades, many researchers have found the same type of interactions in classrooms (see for instance, Kliebard, 1995; Lemke, 1990). Others, have noted that the conception
of teaching as linear is often complemented with the idea of support from material and unambiguous evidence derived from laboratory work to confirm understandings discussed in a lecture (French, 1989; Lunetta, 1998). An interesting observation from this study is that when prospective teachers engaged in argument construction as students they rapidly assumed the practices of teachers, reflecting an overlap between notions of teaching and learning. In other words, to teach and to demonstrate that you have learned (or that you know) become very similar. An analogous process was described by Mortimer (1998) with high school students in a chemistry class. As the course progressed, gradually, the students started to use the teacher’s discourse, and students’ voices disappeared from the context of the classroom. In my opinion, the occurrence of this type of experience, with both prospective teachers and high school students, is indicative that the validation of certain knowledge (in this study, reflected in the process of legitimization) is highly influenced by interactions in the context of learning with those people who hold the authority of knower. In this case, learning experiences would be particularly influential in determining what counts as valid knowledge (Hogan, 2000).

3.2 Argument Construction as Guidance

Another major process involved in argument construction was guidance. Under guidance, two types of processes were identified as occurring: guidance for action and guidance to outcome. The first process reflects much of what Kuhn (1992, 1993) envisioned as being the role of thinking as argument. In her view, thinking as argument would support learners in developing ways of approaching their world promoting a better understanding of their realities. In guidance for action, basic structures of argument as thinking as envisioned and applied by instructors in SCIED 410, supported PTs in pursuing certain ways of thinking about a phenomenon. The experiences with argument construction as guidance for action reflected the potential of thinking as argument. Through argumentation, participants were able to construct explanations for natural phenomena shifting the focus of their activities from solely exploring nature to thinking about nature (Abell, Anderson, & Chezem, 2000; Kuhn, 1993). Thus, this process of thinking significantly affected the way they went about exploring nature.
In contrast, guidance to outcome represents another side of how following a certain mode of thinking can involve a focus on a specific answer. A way of thinking becomes the recipe for the “right” understanding of the world. Note that this was not the purpose of thinking as argument as envisioned by Kuhn. Thinking as argument was intended to involve a dynamic process in which the focus was on the development of modes of inquiry, not finding stable (and static) answers. What causes thinking as argument to shift between dynamic and stable/static; and, sometimes between processes, and answers? It is difficult to establish the causes for this contradictory process, but there are clear parallels between them and participants’ perceptions of learning that emerged in the context of their experiences in SCIED 410.

I identified a common characteristic in the perception of learning of various participants – they all saw learning as being able to distinguish right from wrong. In other words, learning involved getting to a right answer – in this case, the scientifically accepted answer. However, participants had different expectations from their teachers to promote learning. Caroline and Conrad, in particular, expected the teacher to provide some guidance that would help them to find out ways to get to the answer (see p. 234-235, Chapter 7). Matt and Leila thought the role of teachers/instructors was to provide answers directly or indirectly to students (see p. 236-237, chapter 7). In sum, in my view, for students in SCIED 410, guidance for action was driven by an expectation that learning would occur through finding out ways to explore the problem, whereas guidance to outcome would result in learning because it takes you to the answer. Given this, guidance to outcome becomes a constant search for well-defined structures that tell students exactly were to go. My interpretation of these parallels is that guidance does not occur independently of students’ understandings of learning. It is through these lenses that they make sense of what happens in the classroom, and these lenses shape their experiences in the process of argumentation.

If the goal of bringing argumentation to science education is to promote a change in the way people think about natural phenomena, it is critical that a shift from the concern of finding answers to developing processes occurs. Working with mathematics
education, Hiebert et al., (1996) proposed that teachers should problematize knowledge in their classroom. They argue that procedures (or ways to go about explaining a phenomenon or responding to a problem) should become the *problems* for students to examine (p. 15). This approach to teaching helps students to gain more control over these procedures, as well as, in Dewey’s words, helps to find “delight in the problematic” and being capable of “enjoying the doubtful” (Dewey, 1910 p. 228, [as cited in Hiebert et al., 1996]). This is a promising approach for argumentation to overcome limitations revealed in the relationship between learning and guidance. However, in my opinion, the instructor should be cautious about blindly adopting the *problematizing* perspective. Hiebert et al. (1996) advocate a way of teaching that is totally focused on process. They argue that even the topic of the problem being addressed in the classroom is not relevant. For instance, it does not matter if the problem is related to everyday life situations or not. Following an approach that is more aligned with Vygotsky’s thought, my critique to this extreme approach reflects my concern with education goals centered simply on supporting individuals in developing means of knowing. For the Russian psychologist, education was about ends, too (Glassman, 2001). Although Dewey saw in Vygotsky much of a propaganda agenda (Glassman, 2001), I believe that educating involves learning some answers that should always be presented as being related to certain means. (In the case of science education, these ends would be the development of some understandings about science that are scientifically accepted.) Yes, means need to be examined and explored, but *in the context of certain ends*, and vice-versa. To separate means and ends would reverse the focus of education, but would not challenge the notion that the knowledge that we construct is dissociated from particular means.

### 3.3 Argument Construction as Impediment: Opening for Other Processes

The comparison of the categories of argument construction as guidance for outcome and argument construction as impediment bring to surface a contradiction. Some participants are expecting that instructors will provide them with a well-defined structure for thinking, but at the same time, they want to be able to think in diverse ways. It is challenging to fully understand the origins of this contradiction but one can infer that
although they had experienced a certain type of learning in the context of SCIED 410 (and probably in other science courses) there is some dissatisfaction with these experiences and they are willing to try something new, although afraid to take responsibility to do so. The same dissatisfaction with argumentation was observed among high school students who engaged in argumentation about genetics (Zohar & Nemet, 2002). They complained about having to repeatedly approach the same type of problem in a similar way. In SCIED 410, PTs addressed considerably different problems, however, still the repetitiveness of the approach was problematic, both for Leila (who felt uncomfortable with the structure of the argument) and for Matt (who took the elements of the argument as natural elements of rational thinking). We need to seriously consider this dissatisfaction if we want to promote understandings not only about scientific concepts but also of the processes of knowledge construction. Initially, I viewed thinking as argumentation as a relatively open and generalized way of thinking that would give enough room for people to develop and explore multiple ways of making sense of the world (Kuhn, 1993). However, participants did not experience the situated process of argument construction as an open and flexible way of thinking.

The major reason is likely to lay in the context in which thinking as argumentation was situated, in particular, in the way the task was designed and mediated by the dynamics of the classroom. However, in the real world, argumentation will always be situated, and thus, the risk of it becoming a process that excessively narrows possibilities of thinking needs to be attended to. Leila noted that we repeatedly used an “inductive method” and suggested that alternatives to this type of thinking should be allowed, like a deductive approach. In my interpretation, she is struggling to conceive of other ways of thinking about the natural world. This is not an easy task. One possible way to approach the issue is to understand that some openness in classroom activities can facilitate the emergence of new ways of thinking in response to lived experiences. For instance, an alternative to the dichotomy of deductive versus inductive methods of thinking emerged in mathematics classrooms under these types of flexible conditions. Simon (1996) unexpectedly identified a new way of thinking about mathematics
problems (i.e., transformational reasoning) in the context of a research project through the observation of students. He defined transformational reasoning as “mental or physical enactment of an operation or set of operations on an object or set of objects that allows one to envision the transformations that these objects undergo and the set of results of these operations.” (p. 201). What is important is this example illustrates the possibilities that are opened when students can try new ways of going about interacting with problems. It represents evidence that students can contribute to the construction of multiple ways of thinking.

For the classroom to be a fertile context for the emergence of these possibilities, it must be embedded in a culture that is not defined *a priori* by the instructor. Instead, there must be a constant process of construction and reconstruction of the norms for thinking about natural phenomena (Kelly & Green, 1998). In this context, the class does not start with *scientific norms* that are established, but gradually and collectively develops local norms. For example, Kelly & Green (1998) describe a girl who for the first time engaged in an argument to defend her own ideas, and how, after winning the argument, she realized how important it was to be true to her own position. I would add that even if one does not *win* an argument but *learns* from an argument because she/he was faithful to her/his ideas, norms about argumentation could start to change. However, this is a very complex process that is always situated and cannot be programmed; thus, the role of the instructor becomes much more challenging. On one hand, it is natural that instructors feel uneasy when understandings and practices that confront with science emerge in the local context. On the other hand, the instructor/teacher cannot excessively privilege the *official* norms and knowledge “over developing local lines of inquiry” (p. 176). Again, the instructor struggles with the tensions between means and ends for education.

### 3.4 Final Remarks

The study of experiences in situated argument construction considering participants’ perspectives contributed to new notions of argumentation in the context of classrooms. Students can function in a way that does not necessarily reveal what is at the
core of an experience. As students, they are aware of what is valued – the same understandings, behaviors and discourses that teachers hold. For instance, they are able to construct arguments following the criteria established by teachers without necessarily understanding it in the same manner. As students’ perceptions of the experience were examined, the complexity of this experience was revealed, particularly, its situated nature. Meanings about the process of argumentation are constructed in a rich context of interactions between people, institutions, disciplines, epistemologies, cultures, and so forth. To recognize this situated nature of argumentation is essential to provide meaningful learning experiences for our students. These experiences should authentically speak to learners’ own worlds that meet in the classroom. By navigating through multiple and diverse contexts of knowledge and ways of knowing, and by focusing on process and meanings that learners construct, we can, locally and collectively, develop an argumentation for learning science that is rooted in the notion of interaction.
1 Introduction

As I summarized in my final remarks in the previous chapter, there are several important lessons learned in the present study. First, I gained knowledge on the importance of assessing participants’ perceptions to construct more sophisticated understandings of learning experiences. Second, I came to a notion of the experience of argumentation in science education that is much more complex, involving multiple processes as well as being embedded in a network of interactions. Finally, I also recognized that by exploring these complexities and this situated nature of argumentation, new dilemmas and new goals for science education emerge.

However, what are major implications of these lessons for research, practice and research? In this chapter, I will address the major implications of the study for research, practice and policy. Then, I will conclude the chapter by summarizing the experience of the study with the use of a metaphor.

2 Implications

2.1 Implications for Research

2.1.1 A Different Approach to Research on Argumentation and Science Education

I believe one of the major implications for research of the present study, specifically in argumentation but also in other areas of science education, refers to how we approach social phenomena. The present study shows how different dimensions of the world of experiences emerge when the researcher examines participants’ perspectives on argumentation in science education. It was through their perceptions of the
experiences, and the construction of an understanding of their perspectives, that the situated nature of argumentation came to the forefront. Thus, it becomes clear to me that the notion of context as involving interaction must be taken seriously as part of research methodologies in argumentation (and science education). It is fundamental to pay closer attention to this aspect, instead of focusing solely on students’ behaviors. Through the present study, the serious limitations of this last type of research became evident – to construct knowledge based solely on behaviors (including the performance on specific task) can result in serious misunderstandings about the nature of processes that occur, particularly in relation to learning. With this focus, our knowledge about argumentation is inevitably decontextualized, and we lose sight of the interactions that are at the core of learning and argumentation. This perspective should inform future research, thus combining insights derived from the study of behavior with insights derived from the study of participants’ perceptions. For instance, research on students’/learners’ perceptions of experiences combined with research in discourse analysis could provide a better understanding of the interactions taking place in science classrooms and of ways to promote learning, in particular, through argumentation.

2.1.2 Research on Science Teachers Development

Reform documents call for teachers to teach science as argumentation, but there is little research on teachers’ own development in learning to teach this way. This study shed some light on the processes involved in developing subject matter knowledge about science as argumentation. However, virtually nothing is known about how this subject matter knowledge is translated into the context of classrooms to support children’s learning. Longitudinal studies of prospective teachers could give insights into this aspect.

2.1.3 Argumentation, Learning and Schooling

Recently, the interest in the relationship between learning and schooling has increased. In science education, some scholars have recognized how the culture of the classroom can be an impediment for the establishment of other ways of learning science;
in particular, how the focus on information acquisition has been an impediment for the development of inquiry-oriented learning. Usually, the argument is that students become resistant to engage in certain practices. The present study gave further insight into the complexities of the relationships between learning and “doing school” in this context, practices can become other “facts” to be performed in a disconnected way. Future research could provide a better understanding on the nature of this relationship and of the instances in which learning become the driving force of argument construction.

2.1.4 The Complex Context of Argumentation in Science Education

In the study of argumentation in science education, little attention has been paid to the broader context in which students engage in this practice. Argumentation and schooling occurs in a social, historical and cultural context, and so far, we know little about the relationships that emerge from this broader context. The present study indicated that issues of gender could play an important role in the experience of argumentation, contrary to what previous research with informal argument indicated (Kuhn, 1991). These and other aspects should be further explored in the future.

2.1.5 Argumentation as Legitimization and Argumentation as Means to Understanding

Although argumentation in science education has been described as a dialogical and dynamic process, I am not aware of initiatives to represent such a complexity. Consequently, the complexities of argumentation have been overlooked as they are taken for granted. The result has been a focus on elements of a structure and/or on categorizing behavior that end up reflecting a static notion of argumentation. The notions of legitimization and guidance as means to understanding restore part of the dynamic process of argumentation. Again, I believe that through further research into students’ perceptions of argumentation experiences it would be possible to construct better understandings of this dynamic process.
2.2 Implications for Practice

2.2.1 Need for a Holistic Assessment

The present study indicated that the means of assessment that teachers have frequently relied on do not provide appropriate understandings of students’ learning. We are assessing students’ ability to perform tasks without sharing the significance, meanings and feelings that are related to these tasks. Thus, such an assessment is not supporting teachers in achieving the educational goal of promoting learning. To find ways to assess these aspects is very challenging. In SCIED 410, we had a small classroom, our students (PTs) built arguments, they periodically reflected about what they did in the course, they wrote essays, and still, as instructors, we were not able to assess the meanings that were being constructed and reemphasized in our classroom. It was only when I engaged PTs in conversations periodically throughout the course that those surfaced. I am aware that this type of close contact would not be possible in the context of school, but that does not mean that we should simply ignore the issue.

I believe there are no formulas for assessing more significant aspects of learners’/students’ experiences, this is a continuous process. Nevertheless, there are two key elements to that: establishing relationships centered in openness and promoting critical thinking in the classroom. The issue of relationships is very difficult to address, particularly when we consider the context in which they take place and the differences in power that characterize school. As instructors we should, at least, be aware of this relation of power, and how it is reflected in relationships that are established with students, reflecting, whenever possible jointly with students, about ways to improve these relationships. Besides this attentiveness to relationships that are constructed, the teacher

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1 I would rather use the term ‘interactions’ because it better captures the complexity of the context, however I chose ‘relationships’ because I was afraid some readers would lose sight of the social aspect that I want to emphasize here.

2 Baptiste (2002) makes an extensive examination of the issues involved in teaching and how embedded in the ways we teach are a series of complex aspects that interact with each other. Moreover, he proposes a
should express a genuine desire to promote criticism in the context of the classroom. He/she should talk about limitations as well as positive aspects of the experiences, relating them back to his/her past experiences. Invite students to be as critical as he/she is, and use her/his power to reward such type of position (e.g., grades). I believe that being critical is a “harder game to play” for those who had been in the school system for a long time. More important, through this type of “game,” teachers and students can learn more. One inevitably has to reflect about things that you took for granted.

2.2.2 Need for Courses that Provide Diverse Experiences in Science Learning

The experiences in SCIED 410 provided an opportunity for students to reflect about and articulate understandings of science learning, science and school, establishing relationships between all this aspects in a contextualized manner. Not always were the perceptions of these experiences voiced; not always were the constructed meanings fully explored. However, the potential of this type of course is evident to me. Being able to have different experiences and compare them was at the core of participants’ abilities to think about those experiences. SCIED 410 provided students in a science course with a great diversity of experiences and it is there that its strengths rest.

However, it is important to increase, as much as possible, the diversity of experiences early in college students’ education. As we saw, experiences that would promote the inclusion of personal experiences of marginalized groups in science must be also part of science courses like this one. This could be done not only by establishing more concrete connections to the real world (e.g., engaging in questions that are meaningful in their everyday lives, or using evidence from outside of school), but also through the openness to other ways of thinking that sometimes can emerge locally in the context of the classroom. Underlying these types of initiatives is the notion of reducing the rigidity and “impermeability” of structures that organize the thinking about nature in the context of science education. Such structures tend to reinforce inadequate notions of

way to approach this complex process in a more contextualized (and, thus, in my understanding, also more personal) way.
science held by those who do not like science. Moreover, they reduce the opportunities for a sense of responsibility for one’s own learning.

Nevertheless, we should be aware that courses that address only the subject matter knowledge about “science as argumentation” (like SCIED 410) will not be sufficient for teacher development. Educators need to also support the development of a pedagogy of science as argumentation; that is, help future teachers in the process of translating their subject matter knowledge of argumentation to promote children and adolescents’ science learning through argumentation.

2.2.3 Changing emphasis in argument process in the context of science education

Considering the processes of argument construction identified in the present study and when they occur, there are two major implications for promoting experiences with argumentation for science learning in the classroom. First, it would be important to reduce the emphasis on legitimization, as well as challenge the nature of its elements. Legitimization was the prevalent process of argument construction in the SCIED 410 course. Although I recognized legitimization (i.e., a focus on norms that establish what is a valid argument) as an important aspect of argument construction, the focus on norms should not eclipse the search for understandings. We should search for ways to reduce this emphasis. Of course, this problem cannot be considered in disconnection with issues involved in schooling. However, in the context of the classroom, how can the instructor/teacher approach this problem? Since the process of legitimization was centered in certitude and homogeneity, I believe one way to approach the problem would be to challenge these notions. In other words, by changing the nature of the elements constituting legitimization, one could acquire new insights into the value of argumentation for constructing understandings. This way, norms of argument construction could be seen as flexible and context dependent, and more interconnected to the forms of knowledge that are generated.

Second, it is important to emphasize guidance for action over guidance to outcome. Another concern that emerged in SCIED 410 was the occurrence of the process
of guidance to outcome, which reflects students’ focus on finding an answer for the problems that were posed. In this case, we recommend that instructors should adopt practices that shift the focus from answer to process of knowledge construction. In the context of the course, guidance for action would become essential to illustrate processes that are more fruitful in developing “thinking as argument”.

2.2.4 Science Subject Matter Knowledge and Argumentation

In the present study, participants tended to overlook discipline-specific knowledge and strategies in the process of argument construction. There is indication that curricula and software designed with this concern in mind facilitates the use and awareness about discipline-specific aspects. However, it is important to find ways to reemphasize these aspects in other ways. Again, my suggestion is to develop units in which discipline-specific aspects are explicitly embedded in the process of argument construction, and ask participants to engage in critical comparisons of these experiences.

2.3 Implications for Policy

2.3.1 Rethinking Accountability

The first major implication for policy from this study is that assessment centered on performance does not necessarily show evidence of learning. In an era of accountability, much investment has been made to develop large-scale strategies to establish who is learning and who is not. However, at most, tests will assess who is able to engage in certain performances (doing and passing tests), and provide little insight into the learning processes. There must be a shift in educational policies to build trust with teachers at schools. They are the ones who can have a better grasp of what is taking place in their classrooms. This particular change in policies would demand a lot of effort and is probably unrealistic considering the interests involved in accountability. Nonetheless, I insist that we should be more invested in providing resources and strategies to build stronger communities of learners at schools, rather than trying to create
the exams that will “tell us all.” As I noted earlier, it is only through the establishment of relationships that we are going to have access to what is taking place in the classroom in its deeper sense. The focus of policy makers should be on creating better conditions for the establishment of fruitful long-term relationships between students, teachers and parents, creating a system that supports the construction of communities of learning. In my opinion, the first step would be to eliminate the anonymity in which students have found a safe escape. Teachers must know their students and vice-versa. This initiative could involve changes in the operational level (e.g., such as the creation of teams of teachers who work with the same students throughout the year; reduction of the number of students in a class), but also at the financial level (e.g., better salaries for teachers as the demand for dedication to students increases). This is a particular important issue in my country, Brazil, where standardized tests have been introduced a few years ago, and where educational resources are very scarce in comparison to the U.S. In Brazil, public teachers work in overcrowded classrooms, and, in parallel, earn low salaries, having to teach as much sections as possible (sometimes getting other jobs). Issues in science education cannot be taken as disconnected from economic and political issues.

2.3.2 Certainty and Uniformity in Standards for Science Education

On one hand, there is a clear parallel between processes that occurred in situated argumentation (legitimization and guidance for action), and aspects of science that have been emphasized in the current reform (understandings and abilities to do science as argumentation) (National Research Council, 1996). However, the study reveals a dynamic and complex dimension of argumentation in science that is not reflected in reform documents, particularly in respect to including diverse ways of thinking about problems and the situated nature of argumentation in a social cultural context. Argumentation tends to be presented as a single scientific way of thinking: you engage in scientific questions, give priority to evidence, formulate explanations, connect explanation to scientific knowledge, and communicate explanations (National Research Council, 2000). I identified the multiplicity of the processes, as well as the importance of acknowledging different modes of thinking, and this is not present in these documents.
Standards may represent a consensus of the scientific community but this consensus is not shared with our students. I believe that policy makers should take into consideration both the complexities of science argumentation and the possibility of diversity when designing standards, assessments and programs of professional development.

2.3.3 Teacher Certification Programs

Because of a teacher shortage in the U.S., there has been a call to increase the “efficiency” of teacher education programs with the creation of alternative certification programs. The present research indicates that this type of initiative goes against the goals of promoting science learning centered in “science as argumentation” for all. Teacher development takes time and depends on long-term support of teachers educators as well as of their institutions. In the present study, it took one semester for prospective teachers to articulate and develop some of the understandings of subject matter related to “science as argumentation.” If we want them to translate this knowledge into practice, it would take even longer. Policies need to be realistic in this respect and recognize that teacher education take time.

3 Conclusion: Of Labyrinths, Learning, Argumentation and Science Education

At the end of this study, one of the early images I constructed of Leila’s SCIED 410 experiences came back to me. Learners can perceive the experience of engaging in the process of argument construction very differently. Leila felt very confused (not knowing were they were going and how to keep going) and as if she was left alone (not supported by instructors, could not count on the instructor). At the same time, she felt almost oppressed. She had to follow a very specific path, direction, to do specific things, engage in activities that were pre-established, and, above all, she had to get to a certain answer (the “right answer”). These two responses could be seen as contradictory and were particularly puzzlingly to me. How can someone feel abandoned and lost and, at
the same time, controlled and constrained? This may not be an uncommon or rare feeling among college students and adult learners, but I wondered what the implications were in that specific context, and why someone would experience these contradictions while others would not.

A metaphor that I constructed to represent this participant’s feelings was that of a person in a labyrinth, or more specifically, someone in Meno’s labyrinth. The tale of the Minotaur tells that Minos, the king of Crete, asked the architect Daedalus to construct a labyrinth in which he imprisoned the bull-headed man. Since Athens was in war with Crete, every year they had to send men and women who were left in the labyrinth to be devoured by this monstrous creature – in fact, the monstrous creature was the son of Minos’ wife with a bull sent by the god Poseidon. After many years, Theseus was chosen as one of the people that would be sent to the labyrinth. However, he devised a plan to escape his tragic fate with the help of Ariadne, the daughter of Minos, who felt in love with him. He used a rope to navigate through the labyrinth, killing the Minotaur and finding his way out of the labyrinth.

In the labyrinth, one soon gets lost, but cannot look for an exit in different ways; she had to follow a certain path. Interestingly, in this context, getting out becomes a problem that cannot be separated from the very problem of having to navigate this very structured path. The path is not created by you, it is offered (or imposed) by the other (the powerful one). Moreover, there might be only one way out of that labyrinth, and you have to find it as soon as possible because of the Minotaur. Yes, you are dominated by the terror of being devoured by the Minotaur – humiliation in front of peers, problems with the presentation, a bad grade, a GPA that goes down, instructors that will think “less” of you. Finally, you know that the person who constructed the labyrinth and put you in there, Minos (in your mind, your instructor) knows the way out, but you don’t. You wish he/she just told you. If she/he does not, you will have to figure it out by trial and error.

Other participants perceived the experience in a different manner. For them, it was to some extent a different and new experience as learners of science, but they did
have similar experiences in the sense that the teacher/instructor had a less prevalent role, and as learners, they had to figure out things on their own. In general, they appeared to feel as safe and calm as if they were in a familiar environment. (What makes me believe that to some extent that it was not different and not as new.) In fact, they associated little emotion with these experiences – no love, no hate. It appears to be a “very professional” experience (no feelings or more personal connections). And, an experience that did not conflict with their personal orientation.

One way of seeing this experience would be that they were in the same labyrinth as Leila. But they, like Theseus who had a rope when he went in to kill the Minotaur, have strategies to navigate in the labyrinth and make sense of their movements (and, eventually be able to map the labyrinth). They do that without needing someone to tell them the answer. (We should remember that in the myth, Theseus relies on Ariadne to help him to develop the strategy to solve the problem – the rope.)

The metaphor of the labyrinth is richer than one could initially imagine. It not only tells me about Leila and other participants’ experiences, but it also tells me about the experiences of a novice researcher, who also tries to break free from the “well-traveled paths” and “fences” of what she has known as being “research.” As “fences” are built into ‘walls’ the researcher feels, like Leila, obligated to follow a certain route and do things in a certain way. The researcher fears the Minotaur, who will devour her if she does not find the single right way out of the labyrinth. With time and support from more experienced researchers, she learned that to break free from the labyrinths, one has to turn walls back into fences, and explore and construct paths. She realizes that she was also responsible for constructing her own labyrinth.

Furthermore, the significance of the metaphor lies beyond the parallels between experiences of (younger) learners of science and academic research learners. So far, we

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3 (Bauchspies, 2002) talks about how mathematical knowledge is constructed around paths and fences.
have not considered the experience of the Minotaur. If we turn to the Minotaur, what do we see? We have been talking about this creature as feared, violent and dangerous, as if it was a mix of beast and hangman. However, we tend to overlook the fact that the Minotaur is the true prisoner of the labyrinth. Whereas, warriors would have their whole existence outside the labyrinth, the Minotaur was the one confined to the labyrinth for “eternity.” Curiously, warriors were the only ones with the abilities to free the Minotaur from captivity. Theseus was not the executer of the beast, rather he was the one who could save it/him from prison. I see the educator as both Ariadne, who tries to help people navigate through the labyrinth, and Minotaur, who was forced into a role of beast and is trapped in a system that he/she cannot change. As instructors in SCIED 410, we recreated strong structures (a certain valid argument) as we tried to challenge the labyrinth, instead of challenging these structures and relying more on those who could bring new things from the “outside” world (our students). PTs entering the labyrinth, fear this creature, the educator. One way or another, they could not distinguish the Minotaur from Minos. Unfortunately, they could not understand the interaction with the Minotaur as an invitation to escape the labyrinth.

Labyrinths are experienced by men and women, students and teachers, learners and “learned people,” researchers and participants. When we got in this world, it seemed that all those labyrinths were already here, but we have been constructing labyrinths, entering labyrinths, and reconstructing labyrinths. We are Minotaurs, Theseus, Minos, and Ariadnes. Would it be possible to escape from such labyrinths and such roles? Should we escape labyrinths, at all, or are labyrinths just part of our lives? What may look like a labyrinth to you may be just a series of “well-traveled” paths and “fences” for someone else.

4 Only recently, I thought about the Minotaur in a more attentive way. It happened when I overheard a conversation in Webster’s cafe. I would like to thank this anonymous Spanish girl, who was discussing the work of the Argentinean writer Jorge Luis Borges with a friend. The image of the Minotaur that I construct here derived from her ideas. Unfortunately, I never had the “courage” to talk to her and admit that I was hearing her private conversation. Anyway, I learned a lot from her.
Reflecting on our experiences and those of others help us to see the labyrinth(s) and to see the roles we play in keeping the same “plot”(story) going. In my opinion, research and education are not meant to be labyrinths. Labyrinths are too rigid, too powerful and too closed to promote collective construction of knowledge, participation and freedom. My concerns throughout the process focused on how people coming from different perspectives could contribute to a less ‘labyrinthic’ understanding of an experience. These new emerging understandings about an experience have the potential to shed light on different ways of learning science. There was no complete escape from the labyrinth, and no clear alternative to a labyrinth was proposed. Nevertheless, some insights were gained on how we could turn walls into “fences,” how sometimes we could jump fences, and how tunnels and routes can return to be paths. Although, being who I am (and was) not always allowed me to be faithful to my concerns. I was able to tell a story, learning from others, and hopefully, others learned (and will learn) from me, too.

5 In Portuguese there are two different verbs to differentiate to be (ser) and to be in a place or to be in a more temporary/transitory way (estar). I use the verb ‘to be’ in both senses.
Chapter 10
Post–Script
Articulating an Explanation for Variation in Prospective Teachers’ Experiences with Argument Construction

During the defense of the present dissertation one of the issues that emerged was that an explanation for the variation in PTs’ experiences with argument construction was not clearly articulated as part of the study. In this post-script, I intend to address this limitation. I will first provide an overview of the various factors that I identified as influencing the argument construction experience. Then, I will discuss how these factors can change depending on the participants, emphasizing one more time the situatedness of interactions among these factors.

1 Exploring Factors Accounting for the Nature of Experiences in Situated Argumentation

Instructors and prospective teachers met in a classroom twice a week for 2 hours in a university. They engaged in activities together and constructed a series of artifacts across a semester. This immediate and apparently isolated context was in fact, the point of departure for many other contexts: contexts that PTs joined as they arrived as well as contexts that PTs brought into the classroom. In this one physical environment, in which PTs engaged in the same activities and generated similar artifacts, participants lived very different experiences. The striking question is why?. What was going on? Why did Leila feel such a level of discomfort with situated argumentation, whereas Caroline did not? Why did Conrad recognize conflicts, but avoided bringing them up in the classroom? Why did Matt accept the structure of argument construction as a way of thinking, but at
the same time complain about the repetitiveness of this process? It is impossible to give a definitive answer to these questions; however, it also is impossible to ignore them.

What factors account for participants’ experiences with argumentation? In considering this question, I encountered the difficulties of dealing with multiple factors and aspects that were interacting. The challenge for the researcher is not to construct an explanation for the nature of participants’ experiences and the variation that occurs from individual to individual. The major problem is to avoid constructing an explanation that oversimplifies lived-experience and/or portrays people as coherent and one-dimensional. After all, the identification of patterns does imply in the simplification of complexities of the world in order to make sense. How can one find a middle ground, so as not to compromise too much of any of these aspects?

In my case, it was very important to keep in mind that the purpose of identifying patterns and factors that would help to make sense of these patterns was not to construct universal and exhaustive causal relationships. I am solely exploring possibilities to be further investigated in other contexts and with other (and broader) sets of data.

2 Identifying General Patterns in the Occurrence of Experiences

Legitimization was the most predominant process throughout the course, with all the participants experiencing it frequently. However, in my interpretation, this experience was particularly recurrent in the Light Module, constituting the core of argument construction in this case.

All participants experienced guidance for action in argument construction, but for Conrad and Caroline that was a predominant part of the process. Furthermore, in all the modules guidance for action occurred. However, in the Evolution Module, guidance for action not only occurred more frequently, but also acquired a variety of forms. Notably, this was the only module in which evidence played an important role in guiding participants’ thinking. In the Light Module, guidance rarely occurred. In fact, guidance
for action partially failed in this module, since the driving question was confusing instead of helpful for students in this context. However, it should be noted that making claims concise supported students in articulating their ideas, representing instances of guidance for action. Finally, in the Global Climate Change Module, guidance for action did occur, but primarily with respect to using questions to focus.

In my interpretation, all participants talked about the experience of argument construction as guidance as formula, except Conrad. However, for Matt and Leila, guidance as formula was particularly important in the process of argument construction, especially in the Light Module. Finally, the same two participants also perceived the argument structure as not always facilitating the development of explanations. Leila and Matt talked about the experience of argument construction as impediment, particularly in the Light and Evolution modules.

3 Identifying Factors Influencing Participants’ Experiences

In my interpretation, the interplay of three major factors were very important in shaping experiences with situated argumentation in SCIED 410. I define them as being School, Science, and Learner Orientation. In my interpretation, participants explicitly referred to relationships between School and their experiences with argument construction; however, the relationship between these experiences and the other two factors (Science and Learner Orientation) were developed based on patterns and correlations that I inferred from data (i.e., not directly expressed by participants). Under School I included three major elements: tasks (e.g., design of activities and technology);

1 I would like to make it clear that I do not intend to exhaust all of the possible factors involved in participants’ experiences with argument construction. This study occurred in a specific context which include not only particular people engaged in a particular educational initiative, but also involved a particular researcher, using particular methods and particular data sources. All of these aspects imply that in other contexts other factors could emerge (see discussion of causality in Lincoln & Gubba, 1985).
resources (e.g., time); power (e.g., relationship between teacher and students; grades). *Science* includes dispositions toward science, proficiency with science and definitions of science. *Learning* includes processes of learning and what is to be known. Figure 10.1 depicts a representation of these factors. Note that factors are placed in a circle to represent their relationship, and arrows are used to represent the distinction and differences between factors, which can vary depending on participants.

4 The Influence of Schooling

In this section, I will describe in more detail each of the components of schooling. I begin the section with a discussion of more immediate elements of the classroom context, grouped under tasks and resources. Tasks included the curricula and the technology tools that were used. I purposefully start with this aspect because it has been the most frequently addressed by science educators. I will argue that curricula and technology tools can, in part, explain participants’ experiences; however, an approach that focuses on manipulating only this aspect is destined to promote little change in students’ experiences with argumentation. Thus, we have to turn to other aspects of schooling, as well as other factors, such as *Science* and *Learning* to construct a more robust explanation of experiences with argument construction.

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2 Again, I believe it is important to emphasize that, in this study, I do not exhaust all of the dimensions of this immediate context, but only explore the few aspects. For instance, interactions between teacher and students, as well as among students were not a source of data for the study.
Figure 10.1: Factors influencing participants’ experiences. (The dashed lines indicate that these elements were identified through inferences based on patterns of data, whereas, the relationship was interpreted in quotes from participants).
4.1 Legitimization versus Guidance and the Immediate Instructional Context

4.1.1 The Evolution Module and The Light Module

In my analysis, legitimization was perceived as prevalent particularly in the Light Module, whereas guidance for action occurred more frequently and in various forms in the Evolution Module. Notably, in the latter, guidance as formula was not taking place – despite the effort of some participants to engage in this type of experience. In the Global Climate Change Module, as noted earlier, some guidance for action occurred, but not as frequent or as varied as in the Evolution Module. In this section, I will first characterize and contrast the two modules that I saw as most different (i.e., Evolution and Light). Then, I will discuss how these differences may have influenced PTs’ experiences with argument construction. Finally, I will discuss the experiences that occurred in the Global Climate Change Module in light of the explanation that I constructed for the other modules.

The curriculum for the Evolution Module was designed with the goal of promoting a climate of inquiry in the classrooms (Reiser, Tabak, & Sandoval, 2001; Tabak, 1999). Scientific inquiry is described as having students not only developing understandings of scientific concepts, but also engaging in scientific practices (e.g., conducting investigations, constructing explanations, using the discourse of science), as well as developing an understanding of these practices (Tabak, 1999). Importantly, the design of the curricula was oriented by the theoretical perspective of situated learning, in particular by the work of Brown et al. (1989). Accordingly, learning is seen as a process of enculturation into the experts’ culture (i.e., in this case, scientists’ culture). Thus, the focus of both the Struggle for Survival curriculum and The Galapagos Finches software was on supporting learners in this process of enculturation, so students could become producers of scientific understandings by following scientists’ methods. In the context of this curriculum, scientific practices are understood as not only general domain concepts and strategies (e.g., supporting explanations with evidence), but also as discipline-
specific concepts and strategies (e.g., using the notion of a relationship between form and function to construct explanations) (Tabak, 1999; Tabak, Smith, Sandoval, & Reiser, 1996). With this theoretical framework in mind, the designers purposefully chose a probabilistic phenomenon to be investigated through an observational approach instead of an experimental one, requiring the use of comparisons. Moreover, learners were expected to use theories to explain specific situations, engaging in a process of theory articulation (Tabak, 1999).

How were these principles reflected in the activities and tasks in which learners were engaged? In this curriculum, the problem that is posed to learners and the data they used to solve the problem were derived from an investigation on ground finches conducted by biologists Rosalyn and Peter Grant in the Galapagos Islands. During the wet season of 1976, many birds died on Daphne Island. Learners are asked to explain why so many birds died in that period, and why some were able to survive. Learners are expected to explore multiple explanations for each of the questions and to use a data-rich environment to develop and explore these explanations. The technological component of the unit, The Galapagos Finches software, is part of a project called, Biology Guided Inquiry Learning Environment (BguiLE). The software consists of a series of components that allow for the collection of different types of data (graphs, field notes with behavioral observations of birds, environment characteristics), the recording of data, and an electronic journal for explanation building (Reiser et al., 2001; Sandoval & Reiser, 1997a, 1997b). This environment is designed to support the adoption of general and discipline-specific strategies to construct and examine multiple explanations to the problem posed. In sum, curriculum and technology tools complement and support each other in promoting the goals of the unit.

The design of the Light Module, on the other hand, was oriented by a conceptual change framework. More specifically, it focused on raising the status of scientifically accepted concepts (i.e., light travels in straight lines, light refracts, light can be absorbed and reflected). Accordingly, the goal was to promote dissatisfaction with alternative explanations that PTs’ initially held, making scientific ideas intelligible, plausible and
fruitful. Approaches to teaching within a conceptual change framework can vary considerably (Hewson, Beeth, & Thorley, 1998). For instance, conceptual change also was taken into consideration in the design of the Evolution Module curriculum (Tabak, 1999). However, in the Light Module, conceptual change was approached much more as an individual or psychological process than as a socially constructed process (Kelly & Green, 1998). Initially, we, as instructors, were not as aware of this as we should have been. It was our belief that having argumentation as part of the module would promote the negotiation of meaning. Nevertheless, the module was in fact designed with the expectation that by following a certain path, which was determined by the instructors, PTs would discard these alternative explanations and adopt more scientifically accepted explanations. To respond to the problem of Why do we see what we see?, participants engaged in a series of experiments that were designed by the instructors. The experiments were grouped depending on the concepts they addressed (e.g., light travels in straight lines), and were followed by whole class discussions. After that, participants were asked to construct an explanation relating all of the experiments. Notably, the path to the scientific accepted explanation was clearly defined with virtually no possibilities for transgression: PTs were only given pieces of evidence that could clearly illustrate this explanation, they followed a sequence that would lead them to address only certain aspects of the problem, and they were not given any alternative explanations to explore. Moreover, all of the pieces of evidence were experimental evidence.

Interestingly, Progress Portfolio – the technology tool used for argument construction in the Light Module – was designed within a theoretical framework similar to the one that informed the development of The Galapagos Finches software (Edelson, 2001). However, it is a more flexible tool that has content-neutral structures to support investigations involving data-rich technology tools (Loh et al., 1998). Thus, Progress Portfolio can be adapted to different contexts to promote reflective inquiry (Edelson, 2001; Loh et al., 1998). In the Light Module, we used this technology tool mainly for supporting the development of “reflective reasoning and argumentation skills involving coordination of questions, beliefs, and observations” (Loh et al., 1998, p. 2). However,
results indicated that the context in which *Progress Portfolio* was adopted limited the potential of the tool for that kind of support. This is not surprising given that technology tools are just part of a whole complex context intended to promote *science as argumentation* - with the curriculum having a particularly important role (Reiser et al., 2001). In other words, in this case, the curriculum was hindering some of the capabilities offered by *Progress Portfolio*.

*Were these differences perceived by participants? How?* The differences described above were identified in PTs’ comparisons of these two modules. Leila in particular, articulated the way the differences influenced her experiences, in relation to various aspects. First, the transition from the Evolution Module to the Light Module, in my interpretation, was described as involving a change in the types of experiences with argument construction. The following quote illustrates this change:

L: It's hard for me to think about light in terms of what scientists do because... like I'm probably taking this in the wrong direction, but light has been discovered. You know, like I felt like we were just learning about light, we weren't like investigating light. You know what I mean?

I: So, there's something that people know and.

L: Yeah. Like I see science as more of like investigating, you know, hypothesizing. And with light, it was like, you know, I think we were just learning like a lesson. Like light... like someone already like found out the four properties of light and like we were just being taught that, like we weren't... maybe I missed the point of the whole module, but I didn't see us as investigating light, more as just developing an understanding for light. (...) So I guess I would have to say that the finch module is more like what scientists do. Whereas, like the light was just, you know, presenting information and going from there. Like we didn't... we really didn't have to investigate on our own all that much. Whereas, I think that's what a scientists would do.

Leila – Post-Light Module Interview

Leila experienced the Light Module as learning an answer that was already established, whereas the Evolution Module involved responding to a problem that was
still open by adopting scientists’ practices. We should remember that to know the answer was an essential aspect of the process of legitimization.

Consistent with the aforementioned issue was the way in which the use of the software influenced PTs’ experiences. In the following quote from Leila, in which she compared the two technology tools used in each module, the relationship is illustrated:

L: It[Progress Portfolio], basically, just kept everything organized. But I also could have done that in a notebook. If you guys had asked us to write everything down in a notebook, then I could have done that too. I think it was just more of a... it was very convenient, it being on the computer so we could like share pictures. You know, like if you take a picture and put it to the server and we all could share that. And, yeah, it kept things like clean and everything. Like much cleaner and, you know, it was always there, like we didn't have to worry about bringing anything to class because it was always there. So in that way it was helpful. But like it's obviously very different than the finch software because that was more like inquiry based, where this was like just... this was just like... I almost mean like a spreadsheet or something that we were just filling out each time, you know, because we filled out the same form each time but just with a different experiment. So it was more like... like I see that it was helpful but just as like a word processing thing is helpful. You know? Like it was different. Like it's a good technology, but it wasn't... like that piece of technology didn't enhance my understanding of the material. (my emphasis)

Leila – Post-Light Module Interview

Thus, in my opinion, Progress Portfolio was perceived as not supporting argument construction.

L: And now, yeah, I guess in this module I just saw the software as... yeah, just like a place to store our information and it wasn't. Like we could have written anything in those journals and, you know, and that's what we would have written. But umm... like it was totally... like it wasn't... it didn't help... The only way it helped us was to keep us organized. It did not help us by stimulating questions because it was totally... it was like all blank.
You know, when we would get the thing it was all blank for us to fill out. So it didn't help us to stimulate any questions, it didn't help us to formulate any theses or justifications, it was just a place to record information. (my emphasis)

Leila – Post-Light Module Interview

On the contrary, The Galapagos Finches software was perceive as supporting the goal of trying to understand the problem.

L: Well because like... I know this class is all like discovery learning and whatnot, but with the finch module or the Bguile software, I think that that really was like the basics of the class. You know, like that was what we built our argument around like the finch module stuff and like everyday we came to class and we did like, you know, we searched through the software, like we searched through, like looking at different things, pulling up graphs. Whereas, this, like this module, we just came in and I think the majority of the class was doing experiments and then when we went back to the Progress Portfolio it was just more of a recording.

Leila – Post-Light Module Interview

In sum, in my interpretation, there are parallels between the use of Progress Portfolio and legitimization, in the Light Module (recording and making it clear), whereas in the Evolution Module there are parallels between software use and guidance for action (discovery, evidence). Notably, the use of the software is highly influenced by the curricula that is used and the activities that occurred in class.

The descriptions, as well as participants’ perceptions discussed above, illustrate how, in SCIED 410, there were very different modules informed by different theoretical frameworks, and in which technology tools were used (and experienced) in different ways. The Light Module had some of the key elements of legitimization, whereas the Evolution Module had more room to promote argument construction as guidance for action. First, the Light Module conveyed a single clear message, by using unambiguous evidence and not providing room for multiple views (or conflicts). In contrast, in the Evolution Module, PTs encountered a data-rich environment in which they had to
develop multiple explanations. Second, the Light Module was the most concrete module, based on experimentation that consistently provided physical evidence to support the scientific ideas built in class. In the Evolution Module, on the other hand, PTs dealt with observational data and used discipline specific concepts and strategies to build explanations. This supported learners in understanding that science is not always black and white, that scientific knowledge can be problematic, and that theories are the lenses we use to make sense of the complexity of nature. Without being conscious of it, we created a module that provided our students with a good example of what is to teach as legitimization (i.e., the Light Module). Naturally, this influenced PT’s experiences in constructing arguments.

These differences were greatly influenced by the theoretical orientation informing the modules. One important aspect of this orientation was that, in the Light Module, the approach to conceptual change was very restricted, focusing on the status of specific concepts, which was expected to change dramatically (black and white). In this case, there was little concern with situating these concepts in a landscape of other concepts, practices in the field, and aspects of learners’ orientations to the domain knowledge (Alexander, 1998). This assumption of dramatic change and the decontextualization of knowledge created barriers to engaging in experiences of argumentation as guidance. First, this type of dramatic transformation rarely occurs through argumentation (Leitão, 2000); thus, argumentation would be of little value to support learners in better understanding the problem. Second, engaging in argumentation involves developing understandings of criteria to evaluate explanations, and this criteria is highly determined by the context in which argumentation takes place (Zeidler, 1997). Thus, participants tended to rely on general criteria for constructing explanations, rather than thinking about argumentation in the context of physical sciences.

Another aspect of the theoretical orientation that needs to be considered is the perspective(s) underlying the approaches to conceptual change present in each of the modules (the curricula in particular). A socio-constructivist approach to conceptual change involves not only the status of a concept and/or the conceptual ecology of the
scientific field, but also the conceptual ecology of the classroom (Kelly & Green, 1998). In the Light Module, as I pointed out, the approach to conceptual change was very restrictive, whereas in the Evolution Module the approach to conceptual change involved consideration of important elements of the conceptual ecology of the classroom (e.g., the culture of the classroom).

Finally, through the comparison of these two modules, it was possible to learn that even topics that were not as directly connected with students’ everyday lives (i.e., the evolution of finches in Galapagos Islands), can provide a fertile context for experiences that are coherent with thinking as argument. Science educators have emphasized the importance of participants’ personal knowledge in argumentation (Jimenez, Rodriguez, & Duschl, 2000; Kuhn, 1991), particularly in conceiving alternative explanations (Brickhouse, Dagher, Shipman, & Letts IV, 2000). The present research suggests that it is possible for students to have experience with science as argumentation even if the topic is not as connected to their everyday lives, as long as a rich context is provided. In this case, in argumentation, the topic was not as influential in contextualizing knowledge, as was the process through which students learned about that topic (Hiebert et al., 1996). Nevertheless, we know little about the impact that such a disconnection with personal knowledge may have in terms of broadening the gap between everyday understandings and scientific understandings (Panofsky, John-Steiner, & Blackwell, 1990). The experience of argumentation as impediment may offer some insights into this aspect.

4.1.2 The Global Climate Change Module

So far, to construct my explanation for the occurrence of guidance and legitimization I have focused on the modules that I considered most different. What happens when I examine the third module (Climate Change) in light of this explanation?

Recall that in the design of the Global Climate Change Module, both the curriculum and the technology tools used (Progress Portfolio and WorldWatcher) were influenced by a perspective similar to that of the Evolution Module. However, two important differences between the modules that lead me to characterize the Global
Climate Change Module as a *mid-point* module in relation to the other two modules should be pointed out. First, in the Evolution Module, investigation and argument construction were integrated in the same environment, whereas in the Global Climate Change Module they occurred in separate environments (*WorldWatcher* software, and *Progress Portfolio*). Although, in this case, they were better integrated than in the Light Module, they were still separate. Second, the answer for the issue of global warming is still an open question: although there is strong evidence that global warming is occurring, there is intense debate around it. Thus, in this module, participants were invited to participate in the debate, and like everybody else, search for a better understanding of the question. In this respect, the module was even more open-ended than the Evolution Module, in which, although the answer was not defined, there was clearly more evidence to support one of the explanations (i.e., beak size was related to the survival of finches).

On the other hand, in the Global Climate Change Module participants had less freedom to explore the problem in comparison to the Evolution Module. In the *WorldWatcher* activities, PTs were instructed to follow a certain path to construct explanations. However, the fact that PTs had to follow a path for investigation did not imply that only one explanation could be constructed. In other words, they could arrive at different conclusions by the end of the task.

Again, in my interpretation, these differences are reflected on participants’ comments about the module. Conrad, in particular, articulated the differences as he compared the Global Warming module and the Evolution Module.

C: I don't know, I felt this one was... this module was a lot more structured like. And I kind of contradict myself later on when I show you my philosophy. But while we had the freedom to interpret the data however we wanted, it was more like follow this path and look at the data in this order. But maybe not even in an order, but umm... I said it guided our activities [inaudible]. Like in the other modules, we had to pick, like for the finch module for example, we could pick which... like we had to narrow it down to beaks and then move on from there. But this one kind of... there wasn't really a right answer. I guess there wasn't a right answer in the finch module either, but. Do you know what I'm saying?
I'm saying like it guided what we were gonna do instead of... Like, I don't know that we had an approach as much as we followed the approach presented to us by the software.

Conrad – Post-Global Climate Change Module Interview

In my interpretation, Conrad recognized that the types of guidance that were provided in each of the modules were different. In the Global Climate Change Module, although it is through questions that PTs were guided for action, I think that the investigation involved a type of guidance that is considerably close to guidance as formula, since one path to the right answer was identified. On the other hand, although the Global Climate Change Module involved following a specific path, in comparison to the Light Module, it was perceived as involving a type of experience that was closer to guidance than to legitimization, as illustrated in Matt’s comments:

M: I think with the Light Module it was look at the evidence until you find out what the claim is exactly. And with this... Well, it's the same thing. Because in this one you're looking at the evidence until. Or in this... no, in this one you're gonna... it's like a back and forth and I'm gonna look at the evidence, finalize what my claim is and then go back to the evidence and pick and choose the evidence that's gonna support my claim best. That's gonna best support my claim. Because, obviously, I think there's gonna be some that's better than others.

Matt – Post-Global Climate Change Module Interview

Again, I identified in PTs’ perceptions the recognition that technology tools were directly related to the tasks and influenced participants’ experiences with argument construction. For example, Caroline emphasized that differences were related to the technology tools used in each module:

C: And then, technology plays an important role because, you know, in this module it may be not necessarily look at like, you know, taking actual temperatures, except for, you know, the one experiment we did with the CO2 atmosphere and the one that had no CO2 in it or whatever. That one... And... but more or less, you know, like the progress portfolio itself, like as a piece of technology, was really helpful, you know, just in organizing, you
know, the argument. It made it a lot easier. You know... And I think I said this about the other modules too, just like having that mechanism to organize your ideas and your thoughts and your information because you don't like... you know, it's just kind of everything is really pretty much scattered. You have to, you know, find a way to organize everything. You know... And... stuff like that. And I think that takes more time and it takes energy away from what you're really looking for to do, rather than, you know, just like, okay, how are we gonna organize this, you know, you have... and especially with the presentations, I mean we have power-point which is really nice because, you know, we can spend more time planning how we want our presentation to be and what the information is then, you know, how we're gonna present it. So.

Caroline – Post-Global Climate Change Module Interview

Here, I identified a perception that was similar to that of Conrad (p. 304) in the sense that the Global Climate Change Module, because of the structure of the software involved a more restrict guidance than the Evolution Module.

In sum, in my interpretation, similar factors identified through the contrast of the Evolution and Light modules were acting in the Global Climate Change Module. Notably, the uncertainty of the answer to the problem supported guidance for action. However, surprisingly, it did not affect PTs’ actions or ways of engaging in argumentation as much. Guidance for action through questions narrowed considerably the focus of the investigation, creating an environment that limited the occurrence of other types of guidance (evidence, for instance), which involved a more open-ended context. Then, the distinction between guidance for action and guidance as formula became blurrier. Another interesting aspect was that all participants, despite their awareness of the existence of multiple possible perspectives on the issue of global warming, ended up constructing a single explanation, and engaging in legitimization. That is, despite the immediate instructional context, legitimization prevailed. I will further discuss and examine this issue later in the chapter.
In conclusion, the results of the present study suggest that technology-infused curricula informed by a theoretical background which is consistent with the notion of science as argumentation (such as The Struggle for Survival curriculum) not only have the potential to result in more complex and robust scientific arguments, but they also can promote more complex and rich experiences from learners’ perspective. Nevertheless, it is worth noting that I am not arguing that we necessarily need to eliminate modules informed by perspectives other than those with which we are aligned. In the present research, it was through the comparison of their experiences in different modules that participants were able to make a distinction between the approaches in the two modules (see Leila’s comments on p. 299). Thus, if we eliminate these different contexts, participants may not be able to make sense of and articulate the significance of their experiences with argument construction.

4.2 Argument Construction as Impediment and Rigid Structures

It is particularly difficult to make sense of the experience of argument construction as impediment. First, we know little about what participants viewed as alternatives to the process of argument construction that they have experienced in SCIED 410. Second, the participants who most frequently expressed appreciation for the experience of guidance as formula were the same ones who experienced argument construction as impediment. This raises the question, How can one need a rigid structure and feel oppressed by this structure?. As this issue is addressed within the immediate instructional context, these challenges are aggravated even more.

Although we cannot provide a robust explanation of this type of experience based on elements of the immediate instructional context, it is still important to consider how the curricula and the technology tools may have promoted impediment. Prior research indicates that technology tools designed to include a rigid template can lead to experiences similar to impediment. In a study with an initial version of The Galapagos Finches software, Sandoval & Reiser, (1997b) observed that the use of templates reflecting domain concepts sometimes hindered high school students’ capacity to articulate their ideas. The authors argued that when learners were uncertain of their
ideas, following the template made the task of constructing explanations more difficult. In the current version of the software, the templates are available solely as guides, and students do not have to follow this specific structure. In the present study, instructors constructed templates in Progress Portfolio, which required that participants articulated their explanations using claim, evidence and justification. Even when these components were not part of the template (i.e., in the Evolution Module), they were included in the rubric used to grade PTs – who were aware of the criteria used for grading their explanations. These requirements for articulating ideas may have lead participants to experience argument construction as impediment, in a similar way to the high school students in the aforementioned study. This reflects a constant tension for instructors, who have to support participants in developing more robust ways of constructing explanations, and, at the same time, need to avoid imposing barriers for students to communicate their ideas.

4.3 Resources

Another factor of the immediate context that had an important influence on PTs’ experiences were the resources available for participants to construct the arguments. Here, I use the term to refer to those resources that were beyond the control of the instructors. Under this category, I was able to identify only one aspect that impacted PTs’ experiences – time. However, factors other than time could hypothetically be categorized under this category (i.e., location/space).

All participants repeatedly expressed being concerned with finishing the tasks on time: being in a hurry, needing to finish on time, saving time, and so on. The following quote illustrates this type of concern, here voiced by Matt:

M: The only other issue I thought was we were really pressed for time with this one. And we just had so much to do at once. And that... I think that really added to the overwhelming feeling and the stress. Like we were going back and forth between this and that and I think every day, too, my group's experiments weren't working. And I know there were a couple times like Conrad and I were still trying to get the experiment to work and they were discussing like why it happens or something, I completely missed it one day. Like I think
Conrad knew because he had had other classes dealing with it, but I have never had anything like it. So, like I was lost in that sense because our experiment wouldn't work and then we'd miss the discussion about it because we were still trying to get the dumb thing to work and that was bad. That was frustrating. And it helped... or it didn't help with the overwhelming feeling later on when we were trying to understand. Because that was when we were actually dealing with refractions. So in class when the experiment wouldn't work for u... .

Matt – Post-Light Module Interview

More importantly, PTs talked about how time limitations led them to make decisions about the kind of argument they constructed. In the following quotes, Conrad and Matt talk about how time limitations influenced their choice to refrain from exploring multiple explanations and ambiguous evidence in all of the modules.

And the why not weight factor was something that we could never really explain other than we concluded that lower weight resulted in all birds because of lack of food and that, thus, weight was not the trait that allowed for survival. Instead like, even... I would guess that even the bird that died... although, we didn't look into this, had a lower weight because there wasn't enough food there. (...) But we didn't ever have time to go in and check out that theory. That was our theory on that. (my emphasis).

Conrad – Post-Evolution Module Interview

I: And, Conrad, like why did you decide not to discuss this piece of evidence in your argument?
C: I would say that it was because of our position on the issue. Putting that in would contradict wherever you're trying to go. And I know that's not right to exclude evidence that contradicts your argument, but I guess that's [inaudible].
I: So do you think it was mainly... it was related to your willingness to basically just use evidence that would support your idea?
C: Yeah. Ideally, I would have liked to go at the module like presenting both sides of the debate. But there's no way you have time to do that. And so based on our position that we
outlined and like that we were taking the approach of what if we don't do anything and it is humans causing it, we focused on convincing people that that's what we should do.

Conrad – Post-Global Climate Change Module Interview

I: And the fact that you told me that you kind of considered that in class and you discarded that based on your experiments and the class discussions. Did you thought about including that in your argument?

M: Show them the alternatives, you mean?

I: Yeah. Showing that you kind of did consider the alternative, that you discarded.

M: I never considered it, but even if it had crossed my mind, which it might of, I don't remember, but we didn't have time to and that was a big issue too. We barely had enough time to do all this, nonetheless do more, like discuss alternatives.

(...)

I: I was wondering if you thought that could be [inaudible] to support your claim that light travels in straight lines.

M: Well, I think it definitely would have made it a better argument. I think anything you can show refuting or any alternatives would serve to benefit. But we didn't have time to and that's just flat out the case. Like if we had wanted to, we wouldn't have been able to.

(my emphasis)

Matt – Post-Light Module Interview

Notably, when time became an issue, participants chose the route of legitimization; that is, they constructed a clear, unambiguous explanation, and avoided exploring alternative explanations or trying to better understand the complexities of the problem. While this pattern tells us that legitimization received priority in the process of argument construction, it does not explain why it received priority. The other aspects of the instructional context may help us to understand that.
4.4 School Structure of Power

In the previous sections, I discussed how different instructional contexts can facilitate or hinder the occurrence of argument construction as legitimization or as guidance. In spite of different immediate instructional contexts, legitimization was still the predominant experience across all modules in SCIED 410 (e.g., including the Evolution Module). Moreover, priority was given to legitimization in all modules, but we have a limited understanding of why this happened. Thus, it becomes necessary to address this issue by situating immediate instructional context in broader contexts. In this section, I will address the ways in which the immediate context of the classroom, is connected to the structures of power that underlie relationships in the classroom.

My thinking about structures of power involved asking: *Who determines what is appropriate in the context of the classroom? Who dictates what is supposed to be done and how it is supposed to be done? Why do these particular individuals occupy a particular position of power in the hierarchy of the school? And, how do they exercise this power?* Notably, here, I saw a clear relationship with the broader context of schooling and the structures of power that are present not only in the classroom but throughout the school-based education. However, I first, present some specific elements of the context in which these relationships were expressed by PTs in the present study, namely, getting good grades and pleasing the instructors. The comments from Conrad illustrate the first element:

C: I can’t stop. I can’t not write my lab report like that or I won’t do well if I don’t write it like that. So...
I: Do you think you have always to do the same way or there is a right way to do that or a better way?
C: It depends if you're interested in getting a grade or... I mean to get a good grade in the class, yeah, I think there's only one way to do it. And if you don't do it that way, if you're not gonna be graded [inaudible]
I: So, in here, we're asking you to get the grade you have to do...
C: You have to separate the two. And to get the grade in the other class, you have to combine the two.
I: I guess my question, Conrad, is like let's say that you're not being graded on that, what do you think would be a useful way for you and in which circumstances?

C: Well, I definitely think that it's easy to see when you separate evidence and justification. It's easy to... it's also easy to get lost and to separate the two. Kind of like for me, personally, if you show me something and say this is my evidence, like for each part, I want to know what that means. And so... I guess that's why I think that I don't know how good it is for me to separate evidence and justification. I mean in an actual lab environment and if you were out in a lab trying to discover something or prove something, maybe [loss of audio] clearly show how your evidence supports what you're trying to say.

Conrad – Post Light Module Interview

In this quote, it is apparent that participants recognized they had to act in accordance to the criteria of the instructors to get good grades. Moreover, getting good grades was seen as being more important than constructing arguments in personally relevant and appropriate ways, at least in the context of the classroom. In other instances, the importance of pleasing the instructors to get good grades is even clearer. This can be illustrated in the following quote:

L: Peer review is good. Like we've always had really good people. Like everyone in our class is really... Like we've always had good peer reviews. But the main thing was when Carla did it. Because like we can peer review all we want, but like our peer review may be different from what like you guys are expecting. So it was good to know like what the teacher or what the instructor wanted. You know what I mean? So, that was a good way to start. (my emphasis)

Leila – Post-Light Module Interview

For Leila, the feedback from instructors was more important than her peers’ feedback. In my interpretation, this reflects Leila’s awareness that instructors had more power in determining the characteristics of an appropriate explanation, rather than seeing it as collectively determined. Her major focus was not to learn but to know and do what the instructors expected her to know and to do.
In my interpretation, these factors are only examples of broader dynamics involved in being a student at a school and having much less power than teachers/instructors/professors. More important, these examples illustrate how this power is taken for granted, and how it is incorporated in the rationale for learning at school without being questioned. The experience of Conrad in the Light Module (see p. 197-198, Chapter 7) reflects how these dynamics as a whole influence PTs’ experiences with argumentation.

I perceived Conrad’s experience in the Light Module as an example of how someone can have completely different responses to the same problem in different contexts. In class, he did not raise issues about the nature of light and did not include these issues in his argument, whereas during the interviews he was willing to discuss the issues in depth. In her work with high school students, Pope (2001) describes how they behave like chameleons to survive at school. The same image of chameleons comes to my mind when I think about Conrad: he adapted to different contexts. Contexts that he was able to distinguish. Like Conrad, students in Pope’s research talked about the difference between learning and playing the game (see page 177, Chapter 6). However, they added comments about how school was turning them into “high school machines” (Pope, 2001, p. 154). In this process, students do not gain deep understandings of the subject matter, and they do not engage with genuine interest in the activities. Rather, they focus on accomplishing the task to get a good grade (Pope, 2001). Interestingly, some students in Pope’s study argued that it was impossible to survive in the system if you did not do so. In my interpretation, Conrad’s contradictory behavior in relation to his conceptual conflicts in the Light Module would reflected perceptions of the context of SCIED 410 (or college as a whole) that were similar to those of Pope’s participants.

In fact, this type of perception is not a rare one in the context of schooling, and is not exclusive to students. Bloome, Puro, & Theodorou (1989) coined the term “procedural display” to refer to situations in which teachers and students engage in what Pope called doing school:
Teachers and students may enact a lesson, say what “needs” to be said to each other, move through and complete the lesson, without necessarily knowing or engaging academic content; yet, they are constructing an event called a lesson that has cultural significance. (p. 272)

This concept was used by Jimenez et al. (2000) to understand high school students’ argumentation in a Biology class. These authors, used discourse analysis to identify and distinguish instances of “doing science” versus those of “doing school” or doing the lesson. Doing school involved instances in which the focus was on accomplishing the task, and interactions between students were organized around the teacher’s expectations. For example, in Jimenez et al. study, students talked about how the course was about genetics; thus, the problem should be solved using genetics. “Doing science” involved “exchanges when students are evaluating knowledge claims, discussing with each other, offering justifications for the different hypotheses, and trying to support them with analogies and metaphors” (p. 771). Conrad’s example, offers new insights into what is it means to do school. Although he engaged in behaviors like justifying his beliefs, he was not actually engaged in “doing science” (for a discussion on how practices may not have the same meaning in the context of the classroom see Brown & Campione, 1998). Notably, his behavior of doing science involved revealing his uncertainty about particular phenomena, the conflicts and confusions that emerged in face of the scientific problem, and the recognition of limitations in his knowledge that needed to be addressed. Unfortunately, doing science did not occur in the classroom, and Conrad, his colleagues and instructors were unable to benefit from that. There he needed to keep things going in their usual and programmed rhythm.

It is important to note that the search for success at school that led to chameleon behavior does not imply that students lost their pleasure for learning. The participants in Pope’s study were sometimes “extremely focused on their work, passionately committed to doing it the best possible way, and willing to toil long hours until satisfied with the results”... reflecting a “sense of passion, of intrinsic motivation to complete a task well, regardless of grades.” I perceived the same passion, commitment and dedication in
Conrad when we had opportunity discuss science. As instructors we should be deeply concerned with the fact that legitimization came to represent a schooling process at odds with intellectual development.

5 Learner Orientation and Experiences with Argument Construction

The structures of power at work in the classroom explain in part how forces other than the tasks and the resources shaped PTs’ experiences with argumentation. However, the context beyond the classroom must be explored. An important question to which must attend, considering the importance of the power structures, is What are PTs’ perceptions of what is to know and to learn in the context of school? This question is addressed through the construct of learner orientation.

Prior research has indicated that conceptions and orientations to learning have great influence on learners/students experiences in science classrooms (Hogan, 2000; Tobin, Tippins, & Hook, 1995). Participants in the present study had perspectives on learning that were similar to those reported in the literature (Edmondson & Novak, 1993; Martinez, Saudela, & Huber, 2001; Tobin et al., 1995). These orientations were described previously (Chapter 7, section 5), but it is important to emphasize that, in my interpretation, they parallel key elements of PTs’ experiences with argument construction, in particular, the prevalence of legitimization.

To explore these parallels, I conceived of two components constituting participants’ learner orientations: learner orientation in relation to what is to be known and in relation to the process of coming to know.

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3 I acknowledge that abilities to engage in science as argumentation is an important factor to be considered. For instance, students with more experience engaging in scientific inquiry would be more successful in participating in units like the Evolution Module (Tabak, 1999). However, this is not the aspect that is addressed in this section. I am interested in students’ perceptions of and perspectives on learning, and how they affected their learning experiences.
In my opinion, there is a consistent relationship between aspects of these two components and PTs’ experiences with argument construction. For instance, the first component of the construct, that is, what is supposed to be known, could be characterized based on two sub-components. First, to learn was seen as to acquire information, a common notion of learning both among teachers (Martinez, Saudela, & Huber, 2001) and among students (Tobin et al., 1995). A focus on understanding specific concepts derives from such notion. Second, to learn is to be able to know what is right, in the context of SCIED 410, this meant knowing the scientifically accepted answer to the problem. In this respect, participants expected to be able to establish a clear distinction between right and wrong. The second component of the construct, that is, learner orientation in relation to the process of knowing, involved an important aspect necessary to understand the patterns identified in PTs’ experiences. First, doing experiments or seeing some type of concrete evidence was essential for learners. This also was reported in the literature (Martinez, et al., 2001; Tobin et al., 1995). All of these aspects of PTs’ learner orientation – related to both aspects – parallels aspects of legitimization that were particularly emphasized in the Light Module, as we pointed out earlier. To learn is to be able to convey a clear message of what the right explanation is, to focus on specific concepts, and to have concrete information to back up your learning. Furthermore, for some participants, in the process of learning the teacher, the one who holds the knowledge, persuades students that he/she has the appropriate knowledge, using the strategies described above. In sum, PTs’ learner orientations were consonant with the most prevalent experiences with argument construction (i.e., legitimization). This led me to infer that PTs constructed meanings about their experiences in light of their understandings of learning epistemologies.

As I further examined the second component of PTs’ learner orientation, other significant parallels were identified, in particular the roles of teachers and students in the classroom. Some of the participants did not recognize the teacher as having the role of knower who convinces students, and the process of learning as following steps that are pre-determined by the knower (teacher). Instead of expecting the teacher to give them
the answer to the problems (or at least the formula to the answer), these students liked to work more independently and wanted to receive some support from the teacher in terms of how to develop ways to approach a problem. The teacher, then, was more of a facilitator than one who transmits knowledge (Martinez et al., 2001; Tobin et al., 1995). These students had a perspective on learning that is more aligned with constructivism, and more frequently experienced argument construction as guidance for action.

In the literature, it has been reported that prospective teachers rarely see the process of learning from a socio-cultural perspective based on notions of situative learning (Martinez et al., 2001). In fact, our participants did not have these kinds of perceptions. This could easily limit the types of experiences with argumentation that PTs might have. Thus, PTs’ perspectives on learning may act as a barrier to engaging in science as argumentation in the way envisioned by the researchers/instructors [e.g., Polman, 2000 #222]. Notably, none of the experiences derived from the present study reflects such understandings.

I believe that these multiple parallels between PTs’ perspectives on learning and PTs’ experiences resulted from the role perspectives on learning have in determining how PTs construct meaning about what they experienced in the course. Some authors have argued that only through a “process of restructuring the teachers’ epistemological, ontological, emotional and social assumption,” can these perspectives on learning could be challenged (Martinez et al., 2001, p. 792). Part of this process would involve making students’/PTs’ perceptions of learning an explicit element of the process of science learning (Tobin et al., 1990). However, it is worth noting that this is not an easy task. In SCIED 410, participants periodically engaged in reflection about their experiences learning science. Nevertheless, the most significant aspects of their experiences and its relationships with perspectives on learning emerged in the context of the interviews. How can we craft tasks that will support students in such a dialogical way? Moreover, to challenge PTs’ perceptions of learning is difficult, in particular, because they are adult learners, with a long history of learning that informs their perceptions. It also is difficult because they are going to become teachers and enjoying the privileges of such a
perspective in the future. It is in light of this historical context (past and future) that participants make sense of the experiences they live in the present (Dewey, 1997).

6 The Role of Science Experiences

Another aspect that was identified as having a relationship with participants’ experiences was science. This construct is defined here through participants’ definitions of science, their proficiency with science, and their dispositions toward science.

An interesting aspect of PTs’ definitions of science was that all of the participants identified constructing explanations based on evidence as an important aspect of science. However, despite this important commonality, in my opinion, there were significant differences in participants’ definitions of science, reflected in two major trends. On one hand, Conrad and Caroline described science as involving dynamic and complex processes, as illustrated in the following quotes:

I think it was a pretty good representation of what scientists do because, you know, I have an image that, you know, they go and they collect the, you know, just the hard facts, the general data. Then they go back, look for, you know, character... significant characteristics, look for things that are correlated and just kind of like begin focusing more on that. You know... Make notes about it, then going in and putting it all together and then, you know, asking questions, like drawing, you know, conclusions from that. I think it's pretty representative of how like scientific study would be conducted, just because, you know, you start really not knowing much of anything and you just kind of like break it down, you know, and put everything together towards the end. So, I think it was definitely, you know, a good example. I was just reading the article for homework and it was on, you know, inquiry. And umm... I think that's like the best way to learn science, you know, rather than just reading something. And just like, you know, scientists get their information from actually going out there and studying.

Caroline – Post-Evolution Module Interview
C: Yeah. To strive to compile conclusive evidence is what I referred to in my claim as making science so dynamic and exciting. Maybe one side or the other will gather such evidence or maybe not. Either way, science, not one side or the other will prevail. Kind of philosophical. Like that. There's no real winner. I mean it's just after the truth. And I think that should be the nature of science.

Conrad – Post-Global Climate Change Module Interview

Moreover, these participants saw scientists as open-minded:

Well, I think they [scientists] have to like make assumptions but they have to also be objective in the fact that they should consider that it can be other factors rather than just, you know, they can't say, okay, well I'm assuming this, so I'm just not going to assume anything else. They have to have. I think you have to have an open mind, but like open minded skepticism. I think that's what they were calling it. Like, I remember that term from psychologist because when they were studying, you know, different parts of the mind, they had to have open minded skepticism, which was like, you know, be skeptical and be like, you know, I'm assuming this, but also be open minded for, you know, if new evidence would come up to consider different factors.

Caroline – Post-Evolution Module Interview

Conrad, in particular, articulated his understanding that science never reaches a final answer and it is not merely a collection of facts:

C: And the other things I have is about generating theories. I have that most of science isn't fact. And each group had to come up with their theory as to why the birds survived. And there was no way to prove that your theory was either right or wrong. If you had enough evidence to back it, then it was accepted or believed. But that doesn't make it correct, like unchallengeable correct.

Conrad – Post-Evolution Module Interview

Furthermore, he considered making thinking explicit an important part of the scientific process:
C: Yeah, I would. I think it's important for them to realize it did act separate. And I don't think it was ever told to me that they were separate until right now. And, then, you start to see things in different ways when you look at it like that. Like you're able to separate things out and, basically, make a claim that's relevant, not just your thoughts. Does that make sense to you? No?
I: I think you have to clarify more, just because like.
C: Instead of like... like I guess what we were just talking about, like how you said it's all... I said it's all... what is the word I used... how it's common, not commonplace, but...
I: Redundant?
C: Assumed or redundant? I don't know. I can’t think of the word. But you can’t assume anything when you're trying to support a claim. And I think I've done that a lot before. And I think it would be important for students to see that you can’t do that. You can’t assume that. I guess you can’t assume.
I: And you think when you keep everything together, when you don't have to separate evidence from claims, you kind of.
C: Yes, you definitely assume and you... you make broad generalizations a lot. I do that a lot when I write lab reports that relate things that probably cant [inaudible] be related just because I think they might relate to each other. And maybe that's all right in a lab report, but if you're actually gonna be a scientist, you cant do that.

Conrad – Post Light Module Interview

On the other hand, Leila and Matt would identified a clear difference between science and school science in narrative that parallels Conrad’s and Caroline’s notions of dynamic and complex science.

M: I definitely learned that science is very difficult to prove just because of the complexities of this debate. I guess the biggest thing that I've learned is with the finch module, like you'd say, oh, it's really difficult to prove and it could always change, yeah, yeah, yeah, that's science. It could always change. But, then, with light, like I said, it just seemed like a lot of facts. And with this it's definitely just like form your opinion on it, but you're gonna have a hard time proving it one hundred percent true. And the door is definitely always open for further advancements here. If you can come up with some better
way to prove something, you know, that's what both sides are, basically, struggling to do. So, I think that was the biggest thing.

Matt – Post-Global Climate Change Module Interview

Leila expressed similar ideas when comparing the Light and Evolution modules (p. 299). Notably, such a complex notion of science was not always considered to be part of school or SCIED 410 (e.g., the Light Module). Although comparisons between modules and between science and school science may indicate that these participants were aware of the complexities of the scientific endeavor, at the same time, they talked about how science was about finding a single right answer (or approximations of the right answer – see Chapter 6, p. 173 and p. 187). Indeed, the idea that science is about testing hypotheses and about proving (as seen in the previous quote from Matt) was expressed more than one time. Such perspectives are coherent with an understanding of science as reaching a final right answer. Interestingly, this understanding is much closer to what tends to occur in school science, than in science in the academy. Interestingly, this type of understanding is coming from the same participants who were able to more clearly articulate differences between science and school science.

Participants also had different levels of expertise in science. Conrad can be viewed as the PT who was closest to be a science expert, or what some participants would call a science person. As described in Chapter 6, he took AP science courses in high school and many science courses in college (p. 177). Caroline was not an expert like Conrad, however, she had various positive experiences learning science, studying in an affluent district and attending many AP classes. In college, she took only the required courses in science (p. 182). Finally, Leila and Matt had fewer experiences with science. They came from less privileged schools and did not attend AP classes. Leila also noted that, as a child, she never wondered about natural phenomena (Chapter 6, p. 174). Moreover, they described themselves as not being “science people,” and said that this somehow affected their experiences in SCIED 410, as illustrated in Matt’s quote previously (p. 320-321) and in the following comments from Leila:
L: Like I had... I had, you know, I had all the sciences, but I don't think that any of my courses ever... like this is the first time I've ever been dealing with evolution. Like, I didn't have it all in high school. And so I think maybe that's why I found this a little more confusing than like Morris [a colleague who was majoring in Earth Science Education] because he's obviously also like a science major. But, yeah, like this is my first time with evolution, so I really... like I never really questioned it even. You know, I was just like, okay, we're here, you know. I guess I wasn't really... I wasn't really confused about evolution until this class because now I'm like, oh man, it's like everything that I thought is just, you know, public wrongness. You know.

Leila – Post-Evolution Module Interview

L: I'm not a science person and like... and I think that has played a huge factor in this class for me because it's hard for me to look at things from a scientific standpoint. But I am learning how to do that through organization of the claim and evidence. So, when I'm in this class, I'm focused on trying to think about it from a scientific standpoint. When I'm outside of the class, I just don't.

Leila – Post-Light Module Interview

This perception of one’s self (or the other) as a science person or not goes beyond the notion of being able to do science, and, reflects relationships with the other elements of the construct science. First, it is interesting how the very definition of science is affected by the perception of being a science person, as illustrated in the following quote:

L: Yeah. Like the project was more of ... was more of like what I think a scientist would do or would be or how they would conduct themselves. Because Mike and I, we really didn't know how to go about it, so we tried different methods. Like we did more of... like I guess for that little experiment or the little project, I guess we did revert back to a little bit of what we did with the finches because we were just trying different things and doing inquiry into that. So, yeah, like the module, like all that I've been talking about with like that, like that is pertaining to the module because I totally think that like the project was something different because, you know, we didn't really know how we were gonna go about doing it, we weren't....like Joe didn't give us measurements and Joe, you know, like
he totally just, you know, threw us on our own, which was good because we had to do it. And so that, I guess I can see as being what a scientist would do. But as far as the rest of the class, what we did the rest of the time, I think that was just more like presenting information and understanding it.

Leila – Post-Light Module Interview

Like in this case, any experiences in which Leila encountered difficulties were described as being more similar to science and what scientists actually do. In other words, if she does not understand something, this is science. Thus, expertise and definition of science somehow overlap. (Interestingly, the same type of perceptions were reported in a study by Barr & Birke (1998) with women and science.)

Second, participants’ perception of being a science person not only involved ability to engage in science but also dispositions to engage in science. Both Leila and Matt made very clear that they did not have any interest in science (see Chapter 6, p. 172-173 and p. 184-185). More importantly, to engage in science was to search for understanding in a way that was foreign and conflicted with their own ways of thinking about the natural world. In my interpretation, Leila, clearly articulated this view in the quote presented earlier in this chapter (see Leila’s quote in p.322) when she said that outside of the class she would not think about nature form a “scientific standpoint.”

On the other hand, Caroline recognized differences between science and other ways to construct explanations, seeing the first as having well defined norms. However, she did not see this as conflicting with her personality. She took for granted that this was the way people do science. Interestingly, Caroline expressed some interest in learning about nature (Chapter 6, p.183), but at the same time was not particularly enthusiastic about taking courses in science (in her case, the only opportunities to engage in science at college). Finally, Conrad was the most interested in science. Although he recognized a discipline-specific nature of scientific thinking as more structured than other ways of thinking, he appreciated that and considered science to be something he was able to do (Chapter 6, p. 177-178).
In my opinion, the patterns of variation in relation to the elements of science map into the variation in participants’ experiences. In general, participants who had more expertise, who described science as more dynamic, and who did not experience much conflict between their own ways of thinking and what they understood to be scientific ways of knowing, engaged more frequently in argument as guidance for action. On the other hand, participants like Leila and Matt who did not like science, who characterized it as finding the right answer, and who experienced a conflict between their own ways of knowing and that of science, engaged more frequently in guidance as formula and experienced argument construction as impediment. Similar parallels have been identified in the literature, although they did not refer specifically to experiences with argument construction (Bell & Linn, 2000; Tobin, Tippins, & Hook, 1995).

However, it is worth noting that considering that much of Leila’s and Matt’s perceptions of science resulted from limited experiences in the classroom and that these views were challenged in SCIED 410, there is strong indication that definitions, dispositions and expertise in science, were developed in the context of school science learning. As I will discuss in the following section, that is an important aspect of defining interactions between the various factors that influenced participants’ experiences with argument construction in SCIED 410.

7 The Dynamics of Interactions Between Factors in the Context of Participants’ Experiences

So far, I constructed a representation of the factors I identified as influential to experiences with argumentation. However, one should note that I have not yet explored the interactions among these factors (as represented through arrows in Figure 10.1). These interactions are likely to involve some overlap between factors, which could be greater or smaller depending on the very understandings of and experiences with each component of each factor. To understand how these factors can vary and interact with
each other, I will discuss how I positioned each of the participants in relation to all of the factors.

### 7.1 Leila

Leila encountered a series of difficulties and challenges throughout her experiences with situated argumentation. In contrast to other participants, she openly discussed how these experiences were embedded in a series of emotions. From her accounts, I inferred that one of the most powerful factors involved were her dispositions with science. She explicitly talked about not being a “science person” and how it made things harder for her. She also talked about a strong sense of estrangement in relation to science: she did not like science and it had little to do with her. She told how science involves a specific way of thinking that is very structured and always leads to a single answer. In terms of expertise in science, she had little prior knowledge in science and had little interest in knowing the workings of science (she just want to consume products of science). Nevertheless, one should note that her relationship with science derived directly from her past experiences in learning science at school. Thus, for her, there was little distinction between science and school science. Her experiences in Learning science involved a lack of agency (e.g., teacher-centered; use of textbooks) and she expected that teachers continue to play this type of role, providing a great deal of structure that is fundamental in learning. However, at the same time she recognized creativity as an important aspect of learning, and was able to distinguish experiences in SCIED 410 that were more similar to science and those that were not. This apparent contradiction in her learner orientation was reflected in her experiences at school in which she expected to have a structure to follow that was clearly conveyed by instructors. Knowing that she was learning science, she also wanted a structured path to get to the answer; she was aware of her inability to engage in science without that support. But at the same time, Leila experienced a great deal of frustration with the repetitiveness and inflexibility of the course. I speculate that these tensions derived from a partial overlap between meanings about learning constructed at school (and probably particularly in science classes) and meaning she may have constructed in other contexts.
7.2 Matt

Matt, like Leila, experienced a series of difficulties and challenges at various points in the course. However, he talked about conflicts he had with science only in the last interview, after the course had ended. During the course, he shared his concerns with aspects of the school context, such as finishing a task in time, a preoccupation with getting to a right answer, and the absence of guidance from instructors in some instances. His notions about learning overlapped to a great extent with his expectations of instructors in the course, as well as his goal to find an answer to problems, reflecting a perception of lack of agency. I was able to better interpret his focus on the final answer after he told me that he understood argumentation as a way of thinking that underlies any type of human inquiry (e.g., History), but, that in science, one can only get to a single right answer (or, at least, an answer that is closer to right). This and the fact that science was about things and not about people were the major reasons that he was not interested in science. Again, I believe this image of science derived mostly from school were he was formally introduced to (and experienced) something called science. Although Matt did not identify with science, he did not express feelings of estrangement, as did Leila. His interest in science subject matter was described as superficial and restricted to certain topics.

7.3 Caroline

Caroline talked about her experiences in SCIED 410 as a very smooth process. As noted in her profile, her major motivation was to have contact with various ways of learning and teaching. In her view, although learning is a search for answers, the role of the teacher is to provide general guidance. Having experienced that before, she was very comfortable with not having everything told to her by the teacher. However, she took the course because she was required to by her school program, not because she was interested in science. In my interpretation, Caroline was aware of the particulars of science, but she viewed doing science like any other subject at school that she had to take
(and get a good grade). Her goal of being a successful student was seen as more important than how science fit into her world.

7.4 Conrad

Like Caroline, Conrad experienced little difficulty as student in SCIED 410. I say as student because he did experience conflicts at another level. In fact, I identified this as a characteristic of Conrad: an ability to separate the three factors school, science and learner orientation. Science was a major focus for Conrad. During our interviews he talked about his experiences with an emphasis on new scientific concepts that were developed through them. He also noted that he appreciated the structured way of thinking of science, although he did not necessarily equate it to the argument structure in the course. He also characterized science as tentative and sometimes contentious. He was the student with extensive experience in science and mathematics. Nevertheless, in the school context of SCIED 410, he did not see science in the same way. He took into consideration aspects such as grades and time to accomplish an assignment, and consider them a priority. He also noted that he was able to differentiate learning from school, and that they did not always come together. Past learning experiences in science reflected his ideas that learning should involve discussion, initiative on the part of student and guidance from instructors. Establishing a dialogue was seen as fundamental to this process of learning.

7.5 Summary

In Figure 10.2, I tried to represent how the different factors change from participant to participant. For Leila, her image of science clearly overlapped with school and learning. In other words, her notion of science (including all 3 components) was constructed based on school and learning, and later came to inform her understandings of these two aspects. For Matt, there was some overlap, because he also had little experience with science outside the school. However, for him, in SCIED 410 he was not only engaged in a science experience but also a general leaning experience, in which aspects of the school context were considered pertinent (bigger circle). Caroline also was
particularly concerned with schooling aspects when engaged in science in the context of SCIED 410. However, she had more experiences with innovative learning, which contributed to a different understanding of these experiences. Finally, Conrad was equally concerned with all of these aspects, but was able to weigh each of them differently depending on the context. Notably, in his case, there was virtually no overlap between the aspects.

Figure 10.2: How different factors occur and interact differently for each of the participants
8 Interaction of Factors and Experiences in Situated Argumentation

In this section, I will propose some ways in which these factors and their interactions can help us to understand (and reveal) some differences and tensions that I identified in relation to the process of situated argument construction. Thus, instead of trying to address all of the aspects that constituted my responses to the first research question, I will focus on those aspects that appeared to be more interesting from my point of view, and were addressed in the discussion chapter of the dissertation.

8.1 Learning, Science and Schooling in Legitimization

All participants at some point in their investigation engaged in legitimization, the most prevalent process of situated argument construction in SCIED 410. However, considering the differences among participants, the same experience may have been motivated by different or mixed factors.

For instance, all the participants shared the notion that in order to be valid an argument should convey a clear message. In class, Conrad intentionally ignored a conceptual conflict that he held. Later, during the interviews, he was willing to discuss this issue. In my interpretation, this example illustrates how Conrad was keeping the influence of different factors separate in each context. In the classroom, accomplishing the task and getting things going normally were of the utmost importance, whereas in the context of the interviews, his interest for science and for learning could be pursued. On the other hand, such a distinction and the conflict underlying it, did not occur for Leila and Matt. From their perspective, science was made of single answers, and to have a clear message was consistent with both of their notions about learning and about science. Thus, they did not have to behave differently in different contexts.

Another aspect of the relationship between schooling and legitimization is reflected on the fact that one of the most common responses participants (in particular Matt and Conrad) gave to explain why they focused solely on one explanation in constructing their arguments was lack of time. Thus, resources available in the context of
schooling were explicitly pointed as the major factor influencing their experiences in the process of argument construction that led to legitimization.

8.2 Learning and Schooling in Guidance

In many instances, I saw argument building as guidance as a process that people engaged in to learn about the problem. However, how could we say that there was a genuine interest or expectation that learning was occurring. Caroline’s focus on learning was reflected in guidance for action, whereas her focus on schooling was reflected in guidance as formula. For Leila and Matt, an overlap of learning and schooling, lead to the notion that some practices of schooling, such as filling the gaps (in guidance as formula), were seen as a natural part of promoting learning. In this case, they were genuinely engaged in learning, even though their understanding of learning may be limited.

9 Final Comments

In this post-script, I tried to represent the complexities of the factors and the interactions involved in explaining prospective teachers’ experiences with argument construction. In my opinion, the constructs of school, science and learner orientation have the potential to help us to understand people’s experiences with argumentation in a situated manner. However, I believe that these factors need to be better characterized and their interactions further explored as we study the same issues in other contexts and try to establish and make more explicit broader connections between the context of the classroom and other contexts (e.g., culture, gender).
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Appendix A
Description of SCIED 410 Modules

1 The Modules

In this Appendix, a description is provided of the three elements involved in each of the modules: the problem investigated by the PTs, the activities they engaged in, and the software. All modules had three basic types of activities: 1) PTs’ prior understanding of the topic was assessed; 2) PTs were introduced to the technology through activities designed to support them in familiarizing themselves with the software to be used; and 3) PTs had to put their argument in action, discussing their ideas in peer review and presenting their final argument to colleagues. In some cases, a brief history of the module’s development also is provided before its description, so that the reader will have a better grasp of the process engaged in by course designers/instructors before the semester in which the present study was conducted. Then, some of the particularities of the module are addressed, including aspects of the nature of science and argumentation that were not present in other modules. These two aspects are focused on because the process of argumentation as well as the criteria for evaluating arguments are both determined by the context in which argumentation takes place. In the case of scientific argumentation, domain-specific aspects are characteristic to argumentation in the various fields.

It is worth noting that as the leading instructor and designer in the Global Climate Change Module, I was able to provide a more detailed and thorough account of that module’s aspects.
1.1 Evolution Module

The Evolution Module was developed based on technology-infused curricula, the *Struggle for Survival Unit* (for a detailed description see Carney et al., 1999; Reiser et al., 2001). The technological component of the unit, *The Galapagos Finches*, is part of a project called Biology Guided Inquiry Learning Environment (BguiLE).

The original curriculum is composed of four phases that last about thirty classes (periods of 50 minutes). PTs in SCIED 410 were expected to engage in investigations in different fields of science; thus, one of the problems in implementing this curriculum was the limited amount of time available. For this reason, we eliminated activities related to the study of island environments (Phase A in the original curriculum), we did not include a paper-and-pencil investigation of a different problem involving natural selection, and we reduced the amount of time available to conduct the investigation and construct an argument, as well as to prepare the final presentation. On the other hand, we included activities to support learners in using some key concepts of natural selection to frame their investigation, in particular the concept of initial variation.

*A Brief Story of the Module*

This module was piloted in the advanced methods course two semesters before the present study. At that point, time limitations were even greater, so the instructors chose not to include any activities designed to promote a better understanding of natural selection. We did discuss some of these activities from the perspective of science teachers, that is, considering the effectiveness of pedagogical strategies. This first short experience with adapting the *Struggle for Survival Unit* was essential to informing the module’s development when we taught SCIED 410 for the first time. A major lesson that we, as instructors, learned was the importance of including those activities to support PTs’ learning about natural selection. Two major aspects led us to such a conclusion.

1 In class, we usually referred to this module as “the Finch Module”; thus, participants frequently did the same in the interviews.
First, to our surprise, most of the prospective secondary science teachers (including future biology teachers) did not have a scientific accepted understanding about the topic. Thus, it was important for PTs to engage in those activities as learners to develop a better understanding of some basic concepts. Second, PTs tended not to use such basic concepts to orient their investigations and construct their arguments. As instructors, we could always refer back to the introductory activities to support students in conducting their investigation and constructing their arguments.

1.1.2 Description of the Module

The Problem

The problem posed to students and the data they used to solve the problem derived from an investigation on ground finches conducted by biologists Rosalyn and Peter Grant on one of Galapagos Islands. During the wet season of 1976, many birds died on Daphne Island. PTs were challenged to explain why so many birds died in that period, and why some were able to survive. Scientists have reached some consensus regarding what caused the death of so many birds, while there are still uncertainties regarding how some birds managed to survive (Grant, 1985; Grant, 1989). In other words, the task did not involve simply confirming something that has been extensively corroborated by scientists. In that sense, we have an authentic scientific problem.

Phases and Activities

The phases and activities of the Evolution Module are summarized in Table A.1. The module starts with a pre-assessment of PTs’ understandings of the topic. At the beginning of the Struggle for Survival unit, the instructors administered Bishop and Anderson’s (1985) paper-and-pencil questionnaire to assess students’ understandings of evolution. Then, students read the article and discussed the reading in small groups, trying to identify in their responses some of the misconceptions addressed by the authors in the article.
In Phase I of the module, PTs engaged in two low-tech activities that would support them in developing a better understanding of natural selection, namely, initial variation, differential survival, environment pressure, and adaptation as change in frequency of a trait in population. The first concept was the focus of the Variation Lab, whereas all were addressed in the Dot Lab activity (NAS, 1998). In this phase, PTs were also introduced to the problem to be investigated in the module. They watched a video to get a sense of the environment of Daphne Island, as well as the kind of research conducted by the Grants (excerpts from the video What Darwin didn’t see). Finally, they engaged in a paper-based activity in which they used a smaller sample of data on finches’ characteristics than that available in the software to try to identify patterns to describe the population.

In Phase 2, working in pairs, PTs were introduced to software as they investigated ideas/questions that emerged in the paper-based activities. The major focus of this first interaction with Galapagos Finches was on the initial variation of the population in relation to each trait. PTs were asked to develop a journal wherein they would explore questions related to that concept (e.g., Are males different from females in relation to beak size?, How fledglings are different from adults?). The investigation was followed by a whole-class discussion about the patterns that were identified and the ways those patterns could be represented (i.e., different types of graphs). Moreover, during this activity PTs would have an opportunity to become more familiar with The Galapagos Finches software.

In Phase 3, students continued their investigation, looking directly at the two questions driving the module. Initially, the instructors modeled the investigation of the first question to support students’ inquiry. Then, they addressed the questions about the finches’ death and how some were able to survive. Finally, PTs put their arguments into action, discussing their written arguments with another pair, and after revision, presented their ideas in a bigger group using Power Point.
Table A.1: Phases and activities of the Evolution Module

<table>
<thead>
<tr>
<th>Phase</th>
<th>Activities</th>
<th>Software Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessing Prior Understandings</td>
<td>- Bishop &amp; Anderson (1985) paper-and-pencil pre-assessment followed by small group discussion</td>
<td></td>
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<tr>
<td>Day 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase I</td>
<td>- Variation lab</td>
<td></td>
</tr>
<tr>
<td>Evolutionary Biology Concepts</td>
<td>- Dot lab (NAS, 1998)</td>
<td></td>
</tr>
<tr>
<td>Days 2-3</td>
<td>- Introduction to driving-questions</td>
<td></td>
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<tr>
<td></td>
<td>- Video clips from <em>What Darwin did not see</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Paper-and-pencil graphing activity with small set of finch profiles: identifying patterns</td>
<td></td>
</tr>
<tr>
<td>Phase II</td>
<td>- Using Bguile to learn about initial variation in Daphne Island finch population</td>
<td>Bguile: <em>The Galapagos Finches</em></td>
</tr>
<tr>
<td>Initial Variation</td>
<td>- Whole class discussion</td>
<td></td>
</tr>
<tr>
<td>Days 3-4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase III</td>
<td>- Investigating the two driving questions</td>
<td>Bguile: <em>The Galapagos Finches</em></td>
</tr>
<tr>
<td>Investigating Driving Questions</td>
<td>- Exploring Environment Window: learn about the available data</td>
<td></td>
</tr>
<tr>
<td>Days 4-6</td>
<td>- Guided exploration - The predator hypothesis:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Using Data Query, Data Log, and Explanation Constructor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Explore other explanations for question 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Exploring explanations for question 2</td>
<td></td>
</tr>
<tr>
<td>Putting the Argument into Action</td>
<td>- Peer review</td>
<td>Bguile: <em>The Galapagos Finches</em></td>
</tr>
<tr>
<td>Days 7-8</td>
<td>- Presentation of argument</td>
<td>Power Point</td>
</tr>
</tbody>
</table>
1.1.3 Particularities of the Module

Nature of Science: The Role of Theory

In this module, learners are explicitly expected to use the theory of natural selection as a framework as they conduct their investigations and build their explanations. This approach considers science as a theoretically based endeavor. It has the potential to help learners become more aware that scientists do not study natural phenomena in an intellectual vacuum – their investigations are structured around quite specific theoretical and methodological frameworks. Thus, students engaged in scientific inquiry in a manner that involved applying discipline-specific processes (Reiser et al., 2001; Sandoval & Reiser, 1997, Tabak et al., 1996).

Nature of Science: Inquiry in Historical Sciences

The notion that for something to be scientific it has to involve experimentation, manipulation, and control has been commonly found among science learners (Rudolph & Stewart, 1998). It is essential that learners (and future teachers, in particular) experience science in a different manner. Evolutionary biology, as with other historical sciences, represents a different way of doing science that must be part of science education. This type of scientific inquiry involves mostly indirect evidence and occurs in a context in which experimentation is not possible. In this module, PTs worked with data about characteristics of the environment and birds in an attempt to explain the death of many individuals as well as the survival of a few. It would not be possible to perform an experiment that would mimic and control all factors involved in the process considering the complex context (e.g., the island environment, the change in the climate, a period of years). Thus, researchers relied on indirect evidence in an attempt to identify patterns and then examined how these patterns change over time and related patterns to different elements of the complex context.
Argumentation: A single environment permits integration

In this module, argument building and investigation took place in the same environment: the Galapagos Finches software. All of the information that could be used as evidence was secondary (i.e., collected by the Grants) and is available in this single environment. In sum, there was a great deal of integration between the processes of collecting evidence and building an explanation. Such integration is clearly exemplified by the fact that any piece of evidence can be easily imported into the argument-building section of the software and hyper-linked to claims. Moreover, the tool permits some degree of guidance regarding how learners collect and organize evidence: the sources of information are restricted to the software and are organized in accordance with domain-specific strategies, facilitating the adoption of these strategies in the process of data collection/analysis. Finally, another integrative aspect of the environment is that all of the claims that constitute each of the explanations for the problem are to be presented in a single narrative. This has the potential to facilitate the establishment of relationships between various claims. Such an integration was not present in the other modules.

Argumentation: Little emphasis on justification

One important characteristic of the software is its lack of specific scaffolds to support the use of justification. As part of the instruction, we asked learners to use one non-specific scaffold (i.e., a note section in the e-journal that is available for each piece of evidence) as a space for learners to include justification as part of their explanation. Thus, unfortunately, the need for justification was not as emphasized and integrated to other components of the argument as it should have been. In the other modules, justification received as much emphasis as the other components of the argument, and was an integral part of the explanation.
1.2 The Light Module

The Light Module was created mainly by the leading instructor of the module and the professor directing the team of instructors for SCIED 410. It stemmed from an extensive series of experiences that were initiated three semesters prior to the present study and involved other researchers. The Light Module was designed according to a conceptual change framework. Major misconceptions about light were identified beforehand, and activities were designed to challenge these misconceptions. Learners were asked to make predictions about the topic and then to run experiments whose outcomes would conflict with the most frequent misconceptions.

The technological component of this module was constituted by the use of probes to collect and process data, and Progress Portfolio was used to record and reflect about experiences and construct an argument.

A Brief History

The interest in creating a unit to teach prospective teachers about the nature of light emerged three semesters prior to the present study. At that time, the leading instructor for this module in SCIED 410, another graduate student, and a team of researchers used the technology-enriched curriculum of KEI (Bell, 1998; Bell & Linn, 2000) to teach prospective elementary teachers in a science methods course. In this case, learners were confronted with two opposing theories about the behavior of light: Light goes forever until it is absorbed versus Light dies out. They used software available on line to collect evidence and construct arguments in support of one of the theories. They also conducted a few experiments but they were not a major part of the unit.

This initial experience led to a significant transformation of the curriculum when the Light unit was taught for a much smaller number of prospective teachers in an engineering science content course offered in the College of Education. First, instructors noted that when presented with two opposing theories, learners tended to align with one of them and examine evidence according to their personal bias. Thus, during the second round of teaching the Light unit, rather than presenting learners with two theories about
light, they were confronted with an open question, *What happens to light?* The question was posed at the very beginning of the unit in the context of a simple demonstration: when the instructor turn off the lights in the classroom, the room became darker, so what happened to the light that was there? In this new unit, performing experiments became a major part of the unit’s tasks. Learners went through a series of experiment stations in a non-specified order and attempted to answer the question. They could use online resources and the KIE web site as additional resources in responding to the questions, but those became secondary resources. Moreover, learners used the *Progress Portfolio* to record and process evidence as well as to construct their arguments in response to the question.

When SCIED 410 was offered for the first time, in the course of one semester the data for the present study were collected and the Light Module was taught as described above, with the exception of organizing the various experiments into modules to help students break down the problem into smaller units. Thus, for instance, all experiments related to the property of light *reflection* were performed and discussed in the same day, with the same occurring for the other properties of light (i.e., light travel in straight lines, light is refracted). During the present study that structure was preserved, with the exception of a change in the driving question that will be discussed in the next section.

*The Problem*

As discussed previously, the way we framed the problem changed often throughout the development of this module. During the semester in which the present study was conducted, PTs were posed the question: *Why do we see what we see?*. In answering this question, they were expected to learn about the various properties of light (light travels in a straight line, light reflects and is absorbed, light refracts) and how images were formed. Thus, instructors coached PTs to respond to the question *what happens to light?*, instead, when they were constructing their arguments.
Phases and Activities

The phases and activities of the Light Module are summarized in Table A.2. In the second module, as mentioned before, different aspects of light behavior were addressed separately in clusters of activities. Each cluster started by assessing learners’ prior knowledge of a specific property of light (e.g., refraction). In other words, contrary to what happened in other modules pre-assessments also occurred periodically throughout the module. After the pre-assessment, PTs would conduct experiments that were designed by the instructor to test predictions made in the pre-assessment, and, working on the Progress Portfolio, construct an Experiment Page (Figure A.1). Finally, the entire class discussed the results. This cycle was repeated in each phase. In Phase I (called Cluster I), PTs learned about absorption and reflection; in Phase II, propagation of light; in Phase III, reflection; and in Phase IV, refraction. After going through all the modules, PTs built Explanation Pages (Figure A.2) to respond to the driving question, *How do we see what we see?*

Finally, at the end of the module, as in the previous one, the argument PTs constructed was put into action. They again engaged in a peer review of their argument and presented their conclusions using Power Point. However, in this case, their presentation was to focus on an application project. After all the properties of light had been addressed, PTs were given projects involving the use of the knowledge they had acquired about light (e.g., constructing a Newtonian reflector telescope, using principles of refraction to construct an astronomical telescope, a compound microscope and a simple magnifier, explaining the nature of each vision defect).
Table A.2: Phases and Activities of the Light Module

<table>
<thead>
<tr>
<th>Phase</th>
<th>Activities</th>
<th>Software Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessing Prior Understandings</td>
<td>Embedded throughout the module at the beginning of each phase</td>
<td>Progress Portfolio and paper and pencil</td>
</tr>
<tr>
<td>Phase I Absorption and Reflection</td>
<td>- Pre-assessment (making predictions)</td>
<td>Probeware</td>
</tr>
<tr>
<td>Day 1</td>
<td>- Conducting experiments (testing predictions) and constructing Experiment Pages</td>
<td>Data Studio</td>
</tr>
<tr>
<td></td>
<td>- Debriefing</td>
<td>Progress Portfolio</td>
</tr>
<tr>
<td>Learning to use Technology Tool</td>
<td>- Brief Introduction to Progress Portfolio</td>
<td></td>
</tr>
<tr>
<td>Day 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase II Propagation of Light</td>
<td>- Pre-assessment (making predictions)</td>
<td>Probeware</td>
</tr>
<tr>
<td>Day 2</td>
<td>- Conducting experiments (testing predictions) and constructing Experiment Pages</td>
<td>Data Studio</td>
</tr>
<tr>
<td></td>
<td>- Debriefing</td>
<td>Progress Portfolio</td>
</tr>
<tr>
<td>Phase III Reflection</td>
<td>- Pre-assessment (making predictions)</td>
<td>Probeware</td>
</tr>
<tr>
<td>Day 3</td>
<td>- Conducting experiments (testing predictions) and constructing Experiment Pages</td>
<td>Data Studio</td>
</tr>
<tr>
<td></td>
<td>- Debriefing</td>
<td>Progress Portfolio</td>
</tr>
<tr>
<td>Phase IV Refraction</td>
<td>- Pre-assessment (making predictions)</td>
<td>Probeware</td>
</tr>
<tr>
<td>Days 4-5</td>
<td>- Conducting experiments (testing predictions) and constructing Experiment Pages</td>
<td>Data Studio</td>
</tr>
<tr>
<td></td>
<td>- Debriefing</td>
<td>Progress Portfolio</td>
</tr>
<tr>
<td></td>
<td>- Argument construction: Explanation Pages</td>
<td></td>
</tr>
<tr>
<td>Putting the Argument into Action</td>
<td>- Peer review</td>
<td>Progress Portfolio</td>
</tr>
<tr>
<td>Days 5-9</td>
<td>- Project</td>
<td>Probeware (in some cases)</td>
</tr>
<tr>
<td></td>
<td>- Presentation</td>
<td>Power Point</td>
</tr>
</tbody>
</table>
### LIGHT EXPERIMENT

**Experiment Title:**

<table>
<thead>
<tr>
<th>Describe your procedure below.</th>
<th>Graph/Table/Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enter data here</td>
<td>Enter data here</td>
</tr>
</tbody>
</table>

**What were the results of the experiment?**

**What claim(s) can you make based on this experiment?**

Enter data here

Enter data here

---

Figure A.1: Experiment Page in *Progress Portfolio* used by PTs in the Light Module.
HOW DO OUR EYES SEE WHAT THEY SEE?

Draft #:

Describe your explanation below.

Enter data here

Evidence #1:

Enter data here

Evidence #2:

Enter data here

Evidence #3:

Enter data here

Explain how the evidence supports your explanation.

Enter data here

Figure A.2: Explanation Page in *Progress Portfolio* used by PTs in the Light Module.
1.2.2 Particularities of the Module

Nature of Science: Inquiry in Experimental Sciences

In the physical sciences, new scientific knowledge is usually constructed through experimentation. In designing experiments, physicists control and manipulate variables to derive general rules for explaining the workings of the natural world (Rudolph & Stewart, 1998). The same approach is used in other fields such as molecular biology or physiology. In spite of the importance of the experimental approach, many science learners have not had the opportunity to engage in activities that reflect this kind of practice. Too often, experiments in science classrooms represent a set of directions to be followed (which do not always make much sense to the learner), leading to results that must confirm information conveyed by the teacher in a previous lesson (Lunetta, 1998). In this course, we attempted to provide a different experience to PTs: they were to explore a scientific problem and learn about nature through experimentation (Chinn, 1998; Lunetta, 1998; National Research Council, 2000). This would be a unique opportunity to make observations and collect evidence in a fashion similar to that followed by scientists, particularly in terms of reflecting about their results and how they informed and were related to their explanations.

We recognized that the ability to design experiments represents a fundamental phase of inquiry in physical sciences that was not contemplated in the module. Unfortunately, time constrains limited the opportunity to do so in the context of SCIED 410. However, it is important to be aware that the fact that we did not do so, does not imply that the approach adopted was not an innovative experience in the context of science education. The aspect of the Nature of Science that we intended to represent was that science learners could answer scientific questions through manipulation of variables

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2 Lunetta (1998) defined experiment as instances “in which students interact with material to observe and understand the natural world”. The term “materials” could include a wide range of things; in this module the notion of experiment is related to manipulating concrete materials (or hands on experiences), in exclusion to virtual materials (e.g., elements of computer simulations) that could in some contexts be considered ‘materials’.
in a physical system. They would have the opportunity to “describe or explain their hypotheses, methodologies or the nature and results of their investigations” (Lunetta, 1998, p. 251). Moreover, this experience would provide a context in which to contrast historical and experimental sciences, and reflect about differences and commonalities between these fields.

**Argument: Nature of evidence**

In this module, all students had access to the same pieces of evidence: the results of the experiments conducted in class. This aspect differed from the prior modules. Moreover, all pieces of evidence were organized according to the way they would be used to build a certain claim. The evidence was explored in a very structured manner, that is, pieces of evidence that would support PTs’ claims about a specific property of light were explored in the same phase of the module. For instance, experiments on reflection were grouped together to support learners in understanding that the angle of reflection for a light ray is the same as the angle of incidence.

Finally, evidence was explored in the context of a *predict and test* approach, meaning that learners were always using experimentation to confirm/discard a certain hypothesis. In other words, the design of the module forced the learner to commit to a certain hypothesis about what would happen, rather than permitting open exploration of the evidence before making such a commitment. This practice and approach to science is common in some fields and at certain stages of scientific research. As mentioned earlier, it reflects an approach informed by conceptual change theory (Alexander, 1998; Hewson, Beeth, & Thorley, 1998), which recommends this type of design. It is worth noting that the notion of conceptual change in education was developed based on what became the process of knowledge construction by scientists (Duschl, 1994; Kelly & Green, 1998).
**Argument: Exploring a Single Explanation**

In the other modules, the exploration of alternative hypotheses was explicit to a certain degree in the design of the module (e.g., questions in the electronic Explanation Constructor, instructors’ rubric). This was sometimes due to the design of the environment of investigation and argument construction, and sometimes to the very way the driving question was framed (e.g., presenting two opposite positions on the global warming issue from the very start). The Light Module focused on confronting the most common alternative conceptions through discrepant events, to promote a scientifically accepted understanding of light. In sum, in this case, a single explanation for light behavior was considered and became part of the PTs’ argument.

1.3 **Global Climate Change Module**

The third and final module of the course addressed the problem of Global Climate Change (Global Warming). As in the Finch Module, the design of the third module was strongly oriented by the curriculum developed at Northwestern University (Edelson, 2001; Edelson & Gomez). Again, in this case, the original curriculum involved a much more extensive period than that available in the course; thus, it had to be condensed greatly. Notably, the focus became the role of atmosphere in influencing earth’s climate; thus, activities involving the development of a better understanding of other factors were excluded in the adapted module. Moreover, the curriculum was adapted in consideration of some aspects that were to be emphasized, particularly in relation to the nature of science. The parallels and differences between the two curricula are pointed out throughout this section.

I have chosen not to discuss the history of this module’s development separately because it would be difficult to understand how the module was altered without a more detailed description. In this respect, it is enough to say that before the semester in which the present study was conducted the module was taught only once, when SCI ED 410 was offered for the first time.
1.3.1 Description of the Module

The Problem

A few weeks before the module began the U.S. government made polemical decisions in relation to the nation’s policy on global warming. These comments were widely reported in the media. The Bush administration decided that the United States would not adopt Kyoto Protocol recommendations (involving, for instance, mandatory reductions in the emissions of CO₂). This contemporary discussion – which was not part of the original curriculum – was used to introduce the topic of Global Climate Change. PTs were asked to take a position in relation to the issue and advise their representatives. To do so, they worked in pairs as in previous modules, acting as consultants to their representatives. They were to respond to the following questions, which were adapted from the original context: 1) Are global temperatures increasing?; 2) What is causing changes in global temperatures? (Is human activity causing changes in global temperature?); 3) Why is global warming such a big problem? (What would be the consequences of GW? What would be the problem with trying to avoid it?); 4) What would be your recommendations about the issue to the U.S. government?

In the original curriculum, PTs acted as consultants to a foreign country, rather than taking a position from the perspective of their own country. One of the instructors’ concerns was that, in this new context, PTs would tend not to reflect about the issue from other countries’ point of view (e.g., developed countries that signed the Kyoto Protocol; developing countries). Thus, each pair was asked to also consider another country’s perspective on the problem. Each pair was assigned a developed (Germany, Australia, Japan) or a developing (Mexico, China, Nigeria) country. They were asked to characterize the country, make comparisons between that country and the U.S., and consider the questions related to the issue from the perspective of that country.

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3 In the previous semester PTs acted solely as consultants for a foreign country. The instructor felt that at the same time, PTs did not make connections to their own lives and were unable to understand other perspectives (e.g., look at the problem from developed countries’ point of view).
Finally, another alteration in the original curriculum was that the pairs were required to talk about what influenced their response to the problem during the final presentation. PTs were to explain how their perspective (personal position, considering the perspectives of certain country, etc.) influenced or did not influence their work as scientific consultants, and to provide an example that illustrated their point.

**Phases and Activities of the Investigation**

The phases of the investigation are summarized in Table A.3. Note that as in other modules, they were centered in phases centered on assessing students’ prior understandings and a phase in which argument was put into action. Moreover, in this particular module, learning the technology tools occurred quite separately from the investigation; thus, this aspect was presented in a distinct phase.

At the beginning of the module, as with the rest of the course, the instructor created opportunities for PTs to articulate their prior knowledge about the topic. The first activity in this phase (Activity A3 in the original curriculum) was intended to elicit PTs’ understanding of factors determinant of a planet’s climate. The notion that global warming is related to changes in atmospheric composition is directly related to the notion that atmosphere is determinant of climate. Do our students recognize atmosphere as an important factor in climate? After receiving some basic information about the distance of planets from the sun through a diagram of the solar system, PTs were confronted with the question, *What planet is warmer Venus or Mercury?*. They were asked to respond to the question first, individually, using paper and pencil. Then, they were asked to work in pairs in responding in more detail to the question in the Progress Portfolio (Figure A.3). In a second activity of the phase, prospective teachers were asked to talk explicitly about their understanding of global warming. They were asked to react to a short excerpt from a newspaper article that referred to recent decisions about U.S. policy in relation to global warming. Working in pairs in the Progress Portfolio, they were to explain what they knew about global warming, identify possible limitations in their understanding, and take a position in relation to the issue (*Is global warming occurring or not?*) (Figure A.4).
In Phase I of the module, the context of the investigation was characterized. The instructor presented the problem to students, using the newspaper article excerpt from one of the pre-assessment activities (Jehl, 2001), and a fictitious letter from the leader of the house of representatives in which PTs were asked to give advice to their representatives on the matter. Then, with instructors’ guidance, prospective teachers broke down the problem (i.e., producing a report containing advice for U.S. representatives) into major questions to be answered (questions described earlier). In this phase, students were also asked to characterize some key aspects of the context of the investigation. They were presented a profile page of the United States in Progress Portfolio that provided information on the environment, economy, politics, and population of the country. Then they were asked to produce a similar page for the country they were expected to compare with U.S., consulting web sites. Furthermore, the pairs had to construct in the Progress Portfolio a Consultants’ Profile Page (Figure A.5). This page was designed to support prospective teachers in identifying how various perspectives could have influenced their investigation. Finally, at home, prospective teachers read two articles that represented two opposite perspectives in relation to the issue of global warming (Gelbspan, 1997; Jones, 1997), and then reacted to the readings in an electronic thread of discussion.
<table>
<thead>
<tr>
<th>Phase</th>
<th>Activities</th>
<th>Software support</th>
</tr>
</thead>
</table>
| Assessing prior understandings    | - What planet is warmer Venus or Mercury? (WW activity A3)  
| Day 1                             | - Task 2: What do I know about Global Warming? What is my position on the issue?                                                                                                                      | Progress Portfolio |
| Phase I                           | - Letter of the US house of representatives  
| Creating the context—characterizing countries and consultants Day 1-2 | - Country Profiles  
|                                    | - Consultants Profiles                                                                                                                                                                                   | Progress Portfolio Web sites |
| Learning Technology Tools: *WorldWatcher* Day 3-4 | - Building a visualization of temperatures in June 1992  
|                                    | - Making comparisons with measurements taken (WW activities B1-B3)  
|                                    | - Recording conclusions in the *Progress Portfolio*                                                                                                                                                     | *WorldWatcher Progress Portfolio* |
| Phase 4: Are global temperatures increasing? Day 4-5 | - Whole class discussion  
|                                    | - Comparing data on temperature in different time scales  
|                                    | - Consulting web site to see the significance of temperature changes: indirect indications of temperature change                                                                                       | Progress Portfolio |
| Phase 5: What is causing changes in global temperatures? Days 6-7 | - What is Greenhouse effect?  
|                                    | - Greenhouse experiment (WW activity C9)  
|                                    | - *WorldWatcher* software activities:  
|                                    | a) *Factors Effecting Global Climate*  
|                                    | b) *Sources of Greenhouse Gases and Human Activities*                                                                                                                                                     | Probeware – Data Studio *WorldWatcher Progress Portfolio* |
| Phase 6: What would be the consequences of GW? Days 6-7 | - *WorldWatcher* software activities:  
|                                    | a) *Consequences of Global Warming*                                                                                                                                                                     | *WorldWatcher Progress Portfolio* |
| Phase 7 Putting argument in action Day 7-8 | - Peer Review  
|                                    | - Presentation                                                                                                                                                                                         | Progress Portfolio Power Point |
INITIAL IDEAS - Global Climate

What do I know about climate? ... .

Which planet do you think will have a higher temperature? Explain why do you think so.

Enter data here

What factors do you think are most important in determining a planet’s? Build a "concept map" that represents your ideas. (use text boxes, arrow, stick notes). Use the text box below to explain your "model".

Enter data here

Figure A.3: Initial Ideas Page in Progress Portfolio in which PTs discussed their responses to the What planet is warmer? activity.
INITIAL IDEAS - GW

What do I know about Global Climate Change?

Last week reading the New York Times, I was intrigued by an article that starts like that...

_U.S. Going Empty-Handed to Meeting on Global Warming_

By Douglas Jehl

WASHINGTON, March 28 -- With an international meeting of environment officials scheduled to begin on Thursday, the United States will be in the position of having no policy on global warming, which will be the main issue of the gathering.

The Bush administration reconfirmed today that it opposed the Kyoto Protocol, the international treaty to fight global warming, and would not submit it for Senate ratification. (…)

What could you tell me about "global warming" that may help me to understand that article? Make clear what you understand by global warming.

Enter data here

What do you think YOU might learn from reading such an article? What are some questions you have about global warming?

Enter data here

In your opinion, is global warming occurring? Explain.

Enter data here

In your opinion, do human activities have the potential to lead to global warming? Explain.

Enter data here

Figure A.4 Initial Ideas Page in the _Progress Portfolio_ in which PTs discussed their understanding of Global Warming.
CONSULTANT’S PROFILE

Educational Background

Enter data here

Our major strengths and limitations are...

Enter data here

Our position in relation to environmental issues is.  
Aspects of the issue of Global Climate Change that most interest us are...

Enter data here

Enter data here

Figure A.5: Consultants’ Profile Page in the Progress Portfolio used in the Global Climate Change Module.
After being introduced to the context, PTs explored basic principles for using WorldWatcher software (WorldWatcher activities B4 and B5). Instructors hoped that, through this activity, PTs would be able to identify features in WorldWatcher that would be helpful when comparing visualizations (e.g., double mice, arithmetic comparison), to think about better ways to conduct those comparisons, to identify aspects that they should be attentive to, as well as to think about what could be learned from those comparisons (in the Progress Portfolio specifically). However, there was little explicit connection between this activity and the context of the problem that organized the module.

Phase III represented the beginning of the prospective investigation of the issue at stake in the module. During this phase students explored evidence that could help them to elaborate a response to the question, Are global temperatures increasing?. This phase began with a class discussion in which the instructor pointed out that the question to be investigated could sound simple, but people could interpret and address it in different ways. Students were invited to talk about how they understood the question. Two major comments that emerged from the discussion related to how one could tell if there had been a change in temperatures or not: When can one say that a change is significant? Even if there is a significant change, how can one tell whether it is part of a natural cycle (i.e., was expected to happen anyway)? The instructor planned to provide opportunities for PTs to consider these two aspects. Due to the lack of available time, only the second aspect was fully explored in class, while the first aspect was in part explored as a homework assignment.

In class, emphasis was placed on the concept of cycle, discussing PTs’ understanding of a cycle, comparing variations in temperature through time using different scales (one day, one month, one year, 100, 500, and 14,000 years). Then, cycles were identified and explanations conceived for them. Finally, PTs were asked to report to the class what they learned from the graphs that would inform their response to the question, Are global temperatures increasing? After that initial interpretation of the

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4 This activity is described in detail in the original curriculum.
graphs, in the next class the instructor discussed different ways to interpret the graph and the rationale underlying such interpretations. The significance of temperature change was an element of these discussions. Parallel to class discussion, students were asked to read an article that addressed possible alternative explanations for temperature changes and explanations of the natural cycles (Broecker, 1992). They also had to explore a website that presented indirect evidence of the increase in global temperature (http://www.time.com/time/reports/environment/heroes/map).

The last activity in this phase was to build Explanation Pages in the Progress Portfolio in response to the question of phase. Students were asked to use a template designed by the instructor, but were allowed to change the template in any way they wanted.

In Phase IV prospective teachers had to address the second question: What is causing changes in global temperatures? As a starting point, the instructor discussed people’s different responses to the question, which was posed at very beginning of the module: What planet is warmer, Venus or Mercury? The goal of such discussion was to identify some of the major factors that influence global temperatures, and, that consequently could be causing global warming. Time limitations obligated the instructor to focus on the factor that was the major object of debate: the atmosphere. Prospective teachers were introduced to the concept of the greenhouse effect and were given some reading on that topic. After this class discussion, PTs conducted an experiment (which was also part of the original curriculum) to ascertain the extent to which the notion of a greenhouse effect could be verified experimentally. In this experiment, two bottles filled with air, one containing higher concentrations of CO₂ was heated and measurements were taken for about 30 minutes. PTs recorded their ideas first in an Evidence Page in the Progress Portfolio, and later built an Explanation Page (Figure A.6). As in the previous phase, the instructor designed template pages that could be modified according to students’ preferences. The results of this experiment were contradictory: one of the

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5 This reading is part of the original curriculum, which is addressed to teachers, not to K-12 students
groups had the CO₂ bottle reaching higher temperatures, while the other group found the opposite. However, there was no discussion of the results by the entire class.

Another type of activity that took place during this phase of the module involved using the WorldWatcher software to collect evidence that would help PTs respond to the question about reasons for changes in global temperatures. These activities mainly involved making comparisons between visualizations and trying to make sense of differences/similarities that were identified. After doing the activities in WorldWatcher, students were asked to record their ideas in the Explanation Pages, using (and modifying) the template provided by the instructor (Figure A.7). Ideally, prospective teachers would have also constructed Evidence Pages; however, due to time limitations the instructor made the decision to skip that important step. PTs worked independently in pairs in four activities (see Table A.3). The first one referred to Factors Effecting Global Climate, while the following three looked at Sources of Greenhouse Gases and Human Activities.

In Phase V, PTs addressed the question, What would be the major consequences of global warming? using the WorldWatcher software. Two activities were designed by the instructor that were similar to those followed in the previous phase (see Table A.3). In this phase, PTs again built Explanation Pages in the Progress Portfolio after engaging in the activities.

Finally, like in the other modules, PTs shared their arguments with their peers in two different contexts (i.e., peer review and big group presentation). What distinguishes that module from the others was that the peer review was designed to encourage dialogue between the pairs, and to encourage students to apply their understandings of argumentation in evaluating others’ arguments. With these goals in mind, I eliminated from the peer review rubric points, requiring students to provide written comments. Moreover, students were given exemplary questions to use in their peer review activity (Figure A.8).
<table>
<thead>
<tr>
<th>Type here your question</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td><strong>CLAIM</strong></td>
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<tr>
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<tr>
<td>Enter data here</td>
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<tr>
<td></td>
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<tr>
<td><strong>EVIDENCE:</strong></td>
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<tr>
<td><strong>Title</strong></td>
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<tr>
<td>Enter data [graph] here</td>
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<td></td>
</tr>
<tr>
<td><strong>Briefly describe procedures</strong></td>
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<td></td>
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<tr>
<td>Enter data here</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Descriptions of evidence/aspects that you want to emphasize</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Enter data here</td>
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<tr>
<td></td>
</tr>
<tr>
<td><strong>JUSTIFICATION</strong></td>
</tr>
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<td></td>
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<tr>
<td>Enter data here</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Our claim relates to the driving question (specify which driving question)... because...</td>
</tr>
</tbody>
</table>

Figure A.6: Experiment Explanation Page in the *Progress Portfolio* used in the Global Climate Change Module.
Figure A.7: *WorldWatcher* Explanation Page in the *Progress Portfolio* used in the Global Climate Change Module.
With respect to the presentation, this module differed from the others in that learners were asked to use the pieces of the argument that they constructed in class to respond to an issue in the context of their everyday lives. They were asked to propose a recommendation to their representatives and substantiate it with what they had learned during the module. Moreover, as mentioned before, prospective teachers were asked to reflect about the influence of their own values and perspectives in their investigation.

1) Does the claim provide a good response to the question?
2) Is the evidence compelling? Suggest alternative pieces of evidence that could be compelling.
3) Talk about alternative explanations/positions in relation to each driving question.
4) Talk about what would be a piece of evidence that could lead you to discard your claim/ theory.

Figure A.8: Suggested Questions for Discussion of PTs’ Arguments during Peer Review in the Global Climate Change Module.
1.3.2 Particularities of the Module

**Nature of Science: Inquiry in Earth Sciences**

Earth sciences, and in particular Global Climate Change studies, illustrate well the historical sciences for science learners. Although evolutionary biology is also a historical science, in this last module our students had the opportunity to experience aspects of inquiry in the historical sciences that were not fully explored in the Evolution Module. In that context, the focus was on the role of theory in constructing arguments, using a microevolution example. In the Global Climate Change Module, many of the characteristics of the historical sciences are explicitly required to successfully build an argument about global warming.

First, historical sciences deal “with multiple interactions among highly complex systems”. “Scientists had conceived the earth as a complex, dynamic system of vast duration”, in which interactions between elements such as the atmosphere, hydrosphere, lithosphere and biosphere interact (Ault Jr., 1998; Schweizer & Kelly, 2001). Moreover, within the perspective of earth systems science, humans are an important element in these interactions, too (Ault Jr., 1998; Schweizer & Kelly, 2001).

Second, as noted earlier in the description of the Evolution Module, in these complex contexts it is not possible to test hypotheses through experimentation and manipulation of variables. Scientists (and science learners) rely on indirect evidence in a wide range of time and space scales to understand patterns recognized as occurring in the present (Rudolph & Stewart, 1998).

The process of constructing knowledge in these contexts involves various aspects that usually are not represented in physical science, and were not contemplated in the case of microevolution. First, in the particular case of studies in earth sciences, there is a considerable extrapolation, since many of the cues needed to understand past episodes are not available (e.g., data on temperatures for the past 14,000 years is available only for certain areas/periods; scientists make inferences about natural cycles on temperature based on these cycles) (Ault, 1998). Second, the quality of knowledge in earth sciences
is not evaluated solely in terms of greater precision. The worthiness of an explanation or concept is mainly dependent on two aspects: reconciliation with other lines of inquiry in the same field, and integration across scales of time and space (Ault, 1998). Finally, inquiry in earth sciences necessarily involves ambiguity in many respects. In particular, this kind of inquiry involves a great deal of interpretation. As Ault (1998) puts it:

Interpretation is a carefully considered goal of geological explanation – a goal with the same status as a criterion of excellence as the geometrical foundation has for physics. In the simplest sense, interpretation is a retrodiction – a warranted series of inferences yielding a historical sequence of events accompanied by a causal model (when plausible) for their occurrence (p. 206).

Nature of Science: Values and Scientific Controversy

In addition to the domain-specific aspects of earth sciences and historical sciences that were presented in this module, the instructional team expected students to reflect on one important aspect of the nature of science in general: how science takes place in a cultural context in which values and perspectives influence scientific knowledge construction. The global warming issue provides a good illustration of this aspect: the same evidence is available to both scientists who have argued that human activities are causing an increase in global temperatures, and those who believe that changes in global temperatures, most probably, can be attributed to natural phenomena and would have little consequence (or even beneficial consequences) for humans in the future. Moreover, scientific conclusions about global warming are related to (or at least correlated with) the positions these groups take in relation to environmental issues as a whole, their major concerns, and the alliances they established with groups (e.g., oil companies). In fact, both sides use the existence of such relationships to discredit opponents’ arguments, making even more transparent the values that underlie ideas (see, for instance, Broecker, 1992; Gelbspan, 1997; Jones, 1997; Mahlman, 1997; Singer, 1999).

One of the goals of the module was for PTs to reflect about this aspect of science, connect it to their own experiences in the module, and articulate a position.
Argumentation: Nature and sources of evidence

First, the evidence used in building arguments in this module was more complex and diverse than in the previous modules. All of the evidence that learners used to understand the phenomena was indirect evidence. Moreover, they used evidence that involved different scales of time and space, as well as the evidence derived from different sources (e.g., experiments, *WorldWatcher* comparisons, graphs, articles, web sites), coming predominantly from secondary sources.

Components of the Argument: Justification and integration

The nature and sources of evidence in this module were directly connected to two important aspects of the nature of science discussed before: *interpretation* and *integration of lines of inquiry and different scales of time and space*. The ambiguity of evidence and the clear need for interpretation make more apparent the significance of justification in argumentation. Considering that the same piece of evidence can be interpreted differently, it is the way one justifies the use of that piece will make an argument more compelling. Moreover, the very pieces of evidence would be generated through interpretation. For instance, the comparison of visualizations in *WorldWatcher* may be conducted differently by different learners who may attend to different aspects and identify different patterns. Thus, what sometimes may appear to be the same *procedure*, may clearly generate different types of evidence.\(^6\)

The need for integration of multiple lines of inquiry and time/space scales is reflected in the ability to reconcile these multiple aspects in the argument (Ault, 1998). The major implication of this notion of argument construction for learners is the need to combine and relate multiple pieces of evidence to support a single claim. This makes the structure of such an argument much more complex, and may lead to the use of a variety of strategies to ensure the consistency of the argument (e.g., some of our students

\(^6\) It is worth noting that interpretation in this case is not considered from a relativistic perspective. Nevertheless, students can easily take ‘interpretation’ to mean differences in opinion that are equally acceptable. Developing a common meaning is one of the major challenges for the instructor.
chose to generate justifications that integrate multiple pieces of evidence to the same claim).

Components of the Argument: Connecting question to claim

In this module, another component was included in the argument. PTs were asked to establish an explicit relationship between the claim and the question. This element was part of the Experiment Pages in the Light Module and appeared to have the potential to help PTs give significance to their explanations. The instructor reasoned that to explicitly establish such a connection between claim and question had the potential to also support them in identifying limitations in their explanations, because they would have to reflect about how and to what extent the explanations that they had constructed responded to the question.
Appendix B
Software Description

1. Bguile – The Galapagos Finches

The software environment of The Galapagos Finches is organized around three main components – Data Query, Data Log, and Explanation Constructor. In Data Query (Figure B.1), students can investigate the problem by exploring various types of evidence, such as environmental factors (Figure B.2), data about the population (Figure B.3), field notes (Figure B.4), and profiles of individual birds (Figure B.5). Evidence can be selected and stored in the Data Log (Figure B.6), where students can interpret and categorize data. Finally, students build their scientific arguments in the electronic journal or Explanation Constructor (Figure B.7). In this area of the software, students generate claims, connect them to evidence, and rate/evaluate their explanations.

Figure B.1: Data Query

Figure B.2: Environment Window
Figure B.3: Population Window

Figure B.4: Field Notes

Figure b.5: Profile Window

Figure B.6: Data Log

Figure B.7: Explanation Constructor
Progress Portfolio

Progress Portfolio was developed by the Supportive Inquiry-Based Learning Project at Northwestern University's School of Education and Social Policy. The software was designed to support students in conducting long-term inquiry projects using computers (e.g., visualization projects, web-based inquiry projects, explorations with CD-ROMs, simulations, digital libraries, etc.). Progress Portfolio allows students to document and reflect on their work using an integrated suite of screen capture, annotation, organization, and presentation tools. In addition, teachers can guide students in their work through the design of prompts and templates that encourage students to think about key issues.

WorldWatcher

WorldWatcher, a supportive visualization environment for the investigation of scientific data, has similar features to environments used by scientists. Students are provided with the necessary support as they learn to use tools to explore, create, and analyze scientific data.

In SCIED 410, the following features of WorldWatcher were used: data, annotation, interpretive visualization, and analytic visualization. In WorldWatcher, data is distributed in data libraries that support educational activities centered on specific topics. WorldWatcher also provides many of the display features of visualization environments designed for scientific researchers. It displays two-dimensional global data in the form of color maps. SCIED 410 students also recorded notes in annotation windows, and the instructors created dynamic WorldWatcher documents with a notebook feature, created text, multimedia, and "hot" links to specific visualizations. In addition, WorldWatcher provides a number of functions for the mathematical analysis of data.

1 This text was adapted from: http://www.progressportfolio.nwu.edu
2 This text was adapted from: http://www.worldwatcher.northwestern.edu
Appendix C
Description of SCIED 410 NOS Activities

1 Nature of Science Activities

1.1 Mystery Box

This lesson occurred between the Evolution Module and the Light Module. In the Mystery Box activity, PTs were given a closed box. Working in small groups, they were asked to investigate what was inside without ever opening the box. PTs had to elaborate claims, provide evidence to support these claims, and explain how the evidence supported their claim (i.e., justification). Initially, the learners could not touch the box. Later, they were allowed to touch the box and move it. Toward the end of their investigation, the PTs were given instruments, such as scales, rulers and magnets, to learn more about what was inside the box. At the end of each stage, I facilitated a whole class discussion of the claims, evidence and justification generated by each group.

The mystery box activity (or black box) has been used for a variety of purposes (e.g., FOSS). In SCIED 410, the activity was used to stimulate thinking about NOS. PTs were asked to make parallels between the mystery box activity and an assigned reading on NOS. The reading addressed aspects of NOS such as the tentativeness of science, how previous conceptions and subjective aspects influence the way we understand and investigate nature, and how science cannot prove something to be right/true. The PTs were then asked to relate aspects of this activity to their experiences in the Evolution module. As instructors, we feel that one of the most important aspects of this activity is the notion that one’s theoretical framework (in this model, the theory of natural selection) determines the way one investigates nature.
1.2 Oobleck

This lesson took place between the Light module and the Global Climate Change module. Oobleck is another very popular activity in school science, frequently used to motivate younger students to explore and play with materials and/or learn about the states of the matter (e.g., Sneider, 1996). Oobleck is a mixture of water and cornstarch and is considered a Newtonian fluid, that is, depending on conditions of pressure, it behaves like a fluid or like a solid. In this lesson, PTs were asked to explain Oobleck’s behavior, but they did not need to reach a consensual conclusion. The purpose of the activity was to support PTs in making a distinction between observing and describing a phenomena (referred to as laws) and explaining what you have observed (referred to as theories). Thus, learners were asked to make a distinction between the laws of Oobleck and the theories to explain its behavior. Although there are limitations involved in this distinction (see for instance, Hess, 1995), we still believed that pedagogically such a distinction was useful for learners to start to perceive elements of the socially constructed nature of science. The same aspect was explored in a similar way in the last NOS activity of the course.

1.3 Sue

The third and final lesson focusing on NOS was specially designed for this course. In the middle of the semester, the researcher and her adviser traveled to Chicago where they visited Sue, the famous Tyrannosaurus rex. In this exposition, information about Sue was grouped under three categories: facts, theories and speculation (www.fmnh.org/sue/facts.html). In class, working in small groups of 3-4, PTs were asked to examine the same information (without seeing how it was categorized in the museum exposition) and to generate their own system of categories. Then, as a whole class, each group presented their categories and explained their rationale underlying their “system.” Finally, these categorizations were contrasted to the “system” of the Chicago Museum of Natural History, which was considered as just another example of classification that we should understand and consider critically. The lesson aimed to
stimulate a reflection on how scientists construct scientific knowledge, how this knowledge is supported by evidence, and to make transparent our views of scientific knowledge.
Appendix D
Informed Consent Materials

FORM B
PROTECTION OF HUMAN RESEARCH SUBJECTS

- The purpose of this funded project is to systematically examine science software scaffolds and supports within the context of science teacher preparation. The technology innovations being studied were developed by the University of Michigan and Northwestern University. These tools include modeling software, simulations and visualization tools, and electronic notebooks. The common feature across tools is that they were designed to support scientific inquiry.

A series of small studies that explore the following questions will be conducted:

- To what extent do the scaffolds/supports make the computational tools usable?
- To what extent do prospective teachers (PTs) engage in substantial inquiry using the scaffolded/supported tools?
- To what extent do the scaffolds/supports help PTs analyze data and draw conclusions?
- To what extent do scaffolds/supports help PTs plan and follow through with scientific investigations? To what extent do the scaffolds help to build explanations and make sense of data?
- To what extent do the scaffolded/supported tools contribute to the PTs working together during their inquiry?
- To what extent do PTs, in using the scaffolded tools, take on more of the inquiry processes over time?
- What scaffolds and supports seem to be particularly effective?
- Are there preferable orderings for when to employ scaffolds and supports?
- What scaffolds and supports appear to work well with each other?

In connection with another funded project, Learning to Teach Science with Technology (1999-2000), the technology innovations described above have been incorporated into existing SCIED courses for prospective science teachers.

- The principal investigator of this subcontract is Carla Zembal-Saul, Ph.D.

Qualifications:

The investigator is experienced with the population being studied (i.e., prospective teachers of science) and the technology innovations that have been incorporated into the SCIED courses. In addition, she is well-versed in the proposed research techniques.

3. There are no special requirements for or characteristics of the subject population (e.g., gender, age, medical status).
4. Students in SCIED 410, 411, 412, 497F, 458, and ENT 315 will be recruited for participation in the study.

5. As a normal part of the courses listed above, students are required to complete a series of projects/assignments that have been adapted and/or developed to incorporate various applications of technology supported through the grant. Using both qualitative and quantitative methods, student projects will be examined to determine the role of technology tools in learning science as inquiry. Electronic artifacts associated with student projects will serve as the primary source of data; however, other data will be collected: (a) video-taped interactions of participants working with the technology tools, (b) video-taped class sessions, (c) audio-taped interviews, and (d) investigator field notes.

The interview protocols will be tailored to issues encountered and understandings developed by participants during involvement in various technology-enhanced projects. Questions will focus on participants’ understandings of the nature of science and scientific inquiry, as well as science concepts addressed in specific projects.

6. Two SCIED doctoral candidates/graduate assistants (GAs), Patricia Friedrichsen and Danusa Munford, are being partially funded through this grant. Their responsibilities include teaching the technology-enhanced modules and assisting with some aspects of data collection. They will also assist with some aspects of data analysis. Dr. Zembal-Saul will serve in a supervisory capacity with regard to instruction and as coordinator of the research projects. In addition, Dr. Zembal-Saul will oversee data collection, archiving, etc. All specialized equipment needed for the study (e.g., computers, video cameras, web server) will be provided by the grant and by the Science Education Option Area or other Department, College and University resources, such as AV Services.

7. Dr. Zembal-Saul will arrange with SCIED instructors to recruit students from the designated courses during regularly scheduled class meetings. Students will indicate their willingness to participate in the study by signing the attached Informed Consent Form.

8. Given that much of the data for this study is connected with student-generated projects/assignments, there is the potential for conflicts of interest associated with grading.

9. Final project grades will be reviewed by the course instructor and principal investigator.

10. Depending on their level of participation, some participants may receive extra credit. Three levels of participation are possible. Level I will involve the use of electronic artifacts only. Level II will involve 2-3 audiotaped interviews throughout the semester. Each interview will last approximately 45 minutes. Participation at this level will result in 2.5 points being added to the final grade. Level III will involve all Level I & II requirements plus videotaping participants’ interactions with technology tools. Participation at this level will result in 5 points being added to the final grade.

For those students who do not wish to participate at Levels II or III, an alternate equivalent extra credit assignment will be provided (e.g., 5-7 page position paper on a controversial issue in science or science education).

Other potential benefits:
The technology tools that prospective teachers will be learning about as part of this study are directly applicable for use in K-12 classrooms. Findings associated with the study are likely to inform the larger teacher education community regarding the use of technology tools in supporting science teacher learning. In addition, findings will inform subsequent revisions to SCIED courses.

11. Confidentiality safeguards include (a) storing data in a secure location (e.g., locked offices of the faculty member named as principal investigator) and (b) removing identifying information from data and employing codes to track study participants.

12. N/A

13. N/A
INFORMED CONSENT FORM FOR BEHAVIORAL RESEARCH STUDY

The Pennsylvania State University

Title of Project: Analyzing Scaffolding Software in Educational Settings for Science (ASSESS)

Person in Charge: Carla Zembal-Saul, Ph.D.
169 Chambers Building
czemi@psu.edu
(814) 865-0827

1. This section provides and explanation of the study in which you will be participating:

A. The study in which you will participate is part of research intended to explore the role of software scaffolds in supporting the learning of science as inquiry.

B. If you agree to participate in the study, the investigators will keep electronic copies of selected assignments for further examination. In addition, two other levels of participation are possible. Level II will involve 2-3 audiotaped interviews throughout the semester. Each interview will last approximately 45 minutes. Participation at this level will result in 2.5 points being added to your final grade. Level III will involve all Level I & II requirements plus videotaping your interactions with technology tools. Participation at this level will result in 5 points being added to your final grade.

C. With the exception of the interviews, your participation in the study will not extend beyond your normal involvement in the course. That is, there will be no additional requirements associated with course projects/assignments if you agree to participate in the study.

D. If you do not want to participate in this research, you will still be required to complete course projects/assignments; however, your work will not be used in the study. Alternative equivalent extra credit assignments will also be available if you choose not to participate (e.g., position papers that attend to controversial issues in science and/or science education).

E. This study will involve audio and video recording. Only the investigators will have access to these tapes. All audio and video tapes will be destroyed after a period of 5 years.

2. This section describes your rights as a research participant:

A. You may ask any questions about the research procedures and these questions will be answered. Further questions should be directed to Dr. Zembal-Saul.

B. Your participation in this research is confidential. Only the person in charge and other investigators on this project will have access to your identity and to information that can be associated with your identity. In the event of publication or presentation of this research, no personally identifying information will be disclosed.
C. Your decision to participate or not to participate will not be disclosed to the person responsible for grading until after grades have been submitted at the end of the semester.

D. Your participation is voluntary. You are free to stop participating at any time or to decline to answer any specific questions without penalty.

E. This study involves only minimal risk; that is, no risk to your physical or mental health beyond those encountered in the normal course of everyday life.

3. This section indicates that you are giving your informed consent to participate in the research:

**Participant:**

I agree to participate in a systematic investigation of science software scaffolds as an authorized part of the education and research program of The Pennsylvania State University.

I understand the information given to me and have received answers to any questions I may have had about the research procedure. I understand and agree to the conditions of this study as described.

To the best of my knowledge, I have no physical or mental illnesses/difficulties that would increase the risk to me by participating in this study.

I understand that I will receive no compensation for participating, and that my grade in the course will not be altered by my participation.

I understand that my participation in this research is voluntary, and that I may withdraw from the study at any time by notifying the person in charge.

I understand that I will receive a signed copy of this consent form.

__________________________________________  _______________
Signature        Date

**Researcher:**

I certify that the informed consent procedure has been followed, and that I have answered any questions from the participant above as fully as possible.

__________________________________________  _______________
Signature        Date
Date: July 30, 2001
From: The Office for Regulatory Compliance
To: Carla Zembal-Saul
Subject: Research Project: "Analyzing Scaffolding Software in Educational Settings for Science (ASSESS)"
(IRB #00B0797-00)
Date of Approval: August 30, 2000

Approval for use of human subjects in this research project was given for a period covering one year after the project’s approval date. To obtain approval for the next annual period, please complete the attached Continuing Progress Report and Review Form (CPRR) and submit it to this office for the continuing review process.

➢ Renewed approval must be obtained prior to the expiration date of August 30, 2001.

➢ Complete, sign, and submit the enclosed CPRR form ONE WEEK prior to the noted expiration date of approval for this project.

➢ A copy of the INFORMED CONSENT FORM that is currently being used for this project MUST be submitted along with the completed CPRR form.

➢ If applicable, submit any anticipated modifications, revisions, minor changes, etc., for review and approval.

➢ In June, the National Institutes of Health released information regarding a new policy (http://grants.nih.gov/grants/guide/notice-files/NOT-OD-00-039.html) that requires education on the protection of human research participants for all investigators submitting NIH application for grants, proposals for contracts, or receiving new or non-competing awards for research involving human subjects. The new training requirement applies to any proposal submitted or award made on or after October 1, 2000, including awards for proposals already submitted. Please note that investigators will not be able to obtain awards until the training requirement has been met. This requirement will also apply to all those receiving NIH awards for applications that have already been submitted.

➢ As many other institutions have implemented, Penn State has extended this policy to ALL INDIVIDUALS involved in human subjects research under the auspices of Penn State. ALL INDIVIDUALS listed in a human subjects application submitted to the Office for Regulatory Compliance will be required to complete a web-based training course on the protection of human subjects before final approval will be granted for the application. The web address for this training is http://www.research.psu.edu/orc/human.
Appendix E
Nature of Science Questionnaire

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. After scientists have developed a scientific theory (e.g. atomic theory, evolution theory), does the theory ever change?

5. 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?

6. 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 do you think scientists used to determine what an atom looks like?

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1 Adapted from Abd-El-Khalick & Lederman (2000).
Appendix F
Post Modules Interviews’ Guidelines (Sample – Finch Module)

1. What approach/strategy did you use to develop your argument about finch survival? What was your process? In what ways did the software support/inhibit the process of argument construction?

2. Review pre-assessment. How have your understandings about evolution changed throughout the module. Give 1-2 examples from the pre-assessment about which your thinking has changed. What aspects of the module contributed the most to changes in your thinking about evolution (consider class activities and technology)? Try to provide specific examples.

3. Identify 2-3 aspects of the module that you feel most closely reflect what science is and what scientists do. Provide specific examples.

4. If you were planning to teach high school students about natural selection, what (if any) aspects of the module might you use/adapt and why?
Appendix G
Follow-up Interview’ Guidelines

Personal Life
1. How old are you?
2. At what stage you are in the program?
3. Major. How was the process to choose the major? What were the major influences? When did it happen?
4. Where did you leave? Could you describe that place to me? (big city, urban, rural, neighborhood, contact with nature)
5. Tell me a little bit about your family. Do you have brothers and sisters? What do your parents and siblings do? Do you have a dog?
6. Work. What kind of things people did?
7. Organizations: clubs, activism, etc…
8. Things that you like to do. Traveling, hobbies
9. How was the process of moving to college? (where do you leave? Roommates?)
10. Future: How do you see your future? Where would you like to be 5 years from now?
11. Any other things that you would say is an important event or characteristic of your personality

Educational Background
1. What are your past experiences with learning science both IN and OUT of school? Did you enjoy science? Do you consider yourself a successful learner of science? Explain.
2. Think back to the classroom where you had the most positive experiences as learner and describe it. What makes it a favorable memory?
3. Think back to the classroom where you had the most positive experiences as a science learner and describe it. What makes it a favorable memory?
4. Who was your favorite teacher? Explain what makes this person your favorite. Was this the best teacher you had?

Who was your favorite teacher of science? Explain.
Appendix H
Rubric Used to Analyze Arguments

1. Causal Coherence/Causal Structure
   Based on students’ explanations construct a network representation of causal relations.
   a) Description of the causal sequence
      i. Do explanations articulate specific cause-and-effect relations?
      ii. Are causal relations logically connected?
      iii. Are causal relations and their connections explicitly stated?
      iv. Do they consider the possibility of more than one cause? (multiple causal lines)
   b) Do they consider the possibility of multiple factors interacting to produce a phenomenon?
   c) Does the causal structure reflect domain-specific principles? (e.g., selective pressure, change in frequency traits in population, initial variation, differential survival)

2. Evidence
   a) Is there evidence to support each claim?
   b) Is the evidence relevant to the claim?
   c) Do they make valid inferences from data?
      • Do they use principles of knowledge within the domain?
      • Based on population characteristics (e.g., sex & age), do they sort data in appropriate ways?
   d) In which cases do they have more or less pieces of data linked as supporting evidence? What distinguishes parts that are supported with several pieces of evidence and those that are not?
   e) Do they tend to use individual data or representations of population patterns such as graphics? In what circumstances do they use different kind of evidence?
   f) Do they tend to use qualitative data or quantitative data to support their claims? In what circumstances do they use different kinds of evidence?
   g) How do they describe their pieces of evidence (e.g., annotation box in Bguile)? Such descriptions vary depending on the type of evidence (e.g., graphs, field notes)?
   h) Is it possible to identify any changes in these aspects along the unit? (e.g., when do they start to use a type of evidence?)

3. Data justifications
   a) Do students give justification why data are relevant to support a claim?
   b) What kind of justification do they use?
   c) Are there particular instance in which justification is absent/present?

4. Thinking about their explanations (evaluating their explanations)
   a) How do they categorize their explanations? (e.g., accepted completely; accepted with changes)
   b) How do they justify this categorization?
   c) Do they raise questions in their arguments? What kind of questions?
   d) Do they use qualifiers (Toulmin et al., 1979)?

5. Articulation
   a) How do they phrase questions/answers in their argument?

6. Process: How their argument changes
   a) Are new questions are added? How? (linear or pursue multiple paths simultaneously?)
   b) Do they revise questions that were addressed in the past?

1 Based on Kuhn (1991); Sandoval and Reiser (1997)
Appendix I
Questions Developed After Initial Coding

Argument – Whole
1) What an argument does? (Significance)
   argument as record; argument makes one think systematically; argument to show something to the other;
   argument as space for questions to be explored; argument helping to focus; argument space for outrule
   explanations; argument helps to make connections; argument: connect ideas - synthesis; argument: pushing
   learning; argument: not stimulating thinking; argument: not useful if it's not a mystery; argument: no place
   for uncertainties; argument in discovery
2) How do they go about building their argument? (What happens? Strategies)
   Going back and forth from data to the explanation; going backwards; argument: distanced from
   investigation; argument: integrated with investigation
3) What is the value of the argument?
   argumentation: connection to real life situation
4) What participants do to build arguments? (What happens? particular actions)
   backing up claims with evidence; retrieving important/specific pieces of evidence; selecting best
   examples; erasing what was wrong; formulating claims; argument: separating in categories; putting things
   together
5) How do they think about their own explanations? What is the significance for them to evaluate
   explanations? How do they feel about evaluating explanations?
   difficulties in evaluating own explanations; exploring multiple explanations; evaluating as not necessary;
   evaluating is arbitrary; evaluating own explanations; evaluating useful; don't like evaluating; explor.
   multip. expl. - significance
6) How argumentation is different/similar in different contexts?
   argumentation: school x everyday life; argumentation: science x everyday life; argumentation: science x
   non science

Argument - Components
7) What are participants’ understandings of evidence? What do they do with and as they use data as
   evidence? What do they think about evidence? How do they feel about providing/constructing
   evidence?
   evidence x interpretation; backing up claims with evidence; dealing with multiple types of evidence;
   justification x evidence: no difference; availability of evidence affecting the quality of argument (S);
   backing up claims - like; backing up with claims significance; evidence not useful; focus help to understand
   evidence; multiple types of evidence - significance; selecting best examples; interpreting evidence - action;
   having explanation as look at data; looking for significance of data; looking for supporting
   evidence; evidence: concrete to confirm; evidence: conflicting; evidence: unambiguous; justification x
   evidence: hard to separate; justification x evidence: miscellaneous
8) What are participants’ understandings of justification and its relationship with evidence? What do they
   do in building justification? What do they think about justification? How do they feel about
   providing/constructing justification?
   justification x evidence: no difference; justification x evidence: hard to separate; justification x evidence:
   miscellaneous; justification: definition; justification: need for can vary; justification: role
9) What are participants’ understandings of claim? What do they do in building claims? What do they think about claims and its significance? How do they feel about providing/constructing claims? backing up claims with evidence; ; backing up claims - like; backing up with claims significance; formulating claims

10) What are participants understandings of questions?question helps to focus

11) What parallels do participants make between what they did and what scientists do? like scientists; like scientists NOT; scient. ask questions; scient. collect data; scient. construct. explan. from data; scient. focus; scient. have open minded skepticism; scient. have step by step method; scient. keep recods; scient. make assumptions; scient. make connections; scient. need evidence; scient. open end; scient. present their results; scient. processes - significance; scient. test hypothesis; scient. conduct replicable experiments; scient. make thinking explicit

11b. What are their ideas about what science is? (characteristics) nos - field advances from conflicts; nos - you cannot ever accept completely; nos - miscellaneous; nos: laws and theories; science x school

12) In which instances there is interaction with other individuals throughout the investigation (peers and instructors)?

social interaction
what is the significance of the interaction? What do they learn from interaction? How do they feel about the interaction?

Investigation

13) What participants do during investigation? (particular actions)

choosing representations; dealing with multiple types of evidence; exploring multiple explanations; identifying patterns; making comparisons; recognizing multiple ways to analyze/organize data; selecting best examples; focusing action; focusing ; not confident in using scientific concepts; interpreting evidence - action; questionning own process; experiments: performing; experiments: recording.

13b. What is the significance of these actions?

collecting data - significance; experiment leading to learning; experiment was definitely the big thing

13c. What do they feel as they engage in these actions?
going into it really blind; frustration: not going in any direction; fun and frustration; fun generating new evidence; good; confusion - goals; feeling bad: children can do it, I can't; wasn't good; unsolved conflict - weird; frustration: not knowing; concern with understanding scient. content; being lost; overwhelmed; right track: confidence; conceptual conflict;

14) What is the value of engaging in the investigation?

seeing and learning; doing and learning; learning about processes in nature; representations - significance; like scientists NOT

15) What were particular aspects considered particularly valuable?
vital information;

16) What difficulties participants encounter during the process

being unable to make sense of data; conceiving explanations from certain types of data; conceptual conflict

17) In which ways do participants reflect about the decisions they are making throughout the process of investigation?

wondering/questioning

18) What limitations do they identify in the process?
identifying limitations; missing evidence; technology demanding attention; technology limitations; time as impediment to further understand probl.; time pressure; too many questions

19) significance of limitations
missing evidence - confusion
taking for granted limitations/information

20) How do they go about doing things during the investigation?
making decisions based on criteria; focusing; going into it really blind; keeping an open mind
focus help to understand evidence

21) How do they describe the process of engaging in the investigation and building argument as a whole?
open-ended; long process; break and put together; puzzle; course

22) What drives/guides them through the investigation?
Intuition; using scientific concepts

23) What orientation they have as they engage in the investigation?
keeping an open mind

24) What are meaningful experiences in their learning throughout the investigation?
argument: pushing learning
experiment leading to learning; learning about significance; learning from presentations; learning from project; learning from the instructor telling;

25) What are they getting out of the experience? What is the significance of experience as a whole?
making connections; science concepts x scientific inquiry
connection to real life

26) Social interaction (when it occurs, what do they learn from those experiences, how do they feel?)
Social interaction

Other aspects:
1. Discipline specific knowledge
Using scientific concepts; scientific concepts significance
Prior knowledge/
prior knowledge in content knowledge; rethinking prior knowledge; prior knowledge - significance

2. Who are these participants?
learner self; self and argument; science and self; self

3. Ideas about teaching and learning science
teaching - exemplary; science learning; parallels between own experience and teach. recom.; own teaching;
role of the teacher; scaffolding helpful; guidance is valued; technology: role of; inquiry; science x school ; structure of task
VITA

Danusa Munford was born in São Paulo, Brazil on February 26, 1971, being the second daughter of William Munford and Marilene Munford. In 1989, she entered the University of São Paulo. She concluded her B.S. in Biological Sciences in 1993, and received her teacher certification in 1997. In 1993, she started working at the Laboratório de Estudos Evolutivos (Laboratory of Evolutionary Studies) at the Biosciences Institute, where she continued working until 1998 when she obtained her M.S. studying the origins of native Americans based on the analysis of archeological skeletal remains.

Her experiences as science educator started in 1994, when she taught biology in a public high school. In 1996, she participated in a project of the University of São Paulo with an underprivileged community in rural São Paulo State. From 1997 through 1999, she participated in a project of professional development for public school teachers organized by the Secretary of Education of the State of São Paulo. In 1999, Danusa moved to State College, Pennsylvania, to start her PhD in Science Education in the Department of Curriculum and Instruction in the College of Education at Pennsylvania State University.