

AN INTERPRETIVE STUDY OF HIGH SCHOOL STUDENTS' BIOLOGICAL
EXPLANATIONS ELICITED THROUGH THE SCIENCE WRITING HEURISTIC

by

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(Under the Direction of Carolyn S. Wallace)

ABSTRACT

The purpose of this qualitative interpretive research study was to examine high school biology students' written scientific explanations that were provided during six biology laboratory investigations. The research study specifically aimed to identify the understandings that the students attached to scientific explanations, characteristics of students' scientific explanations, the nature of students' epistemologies related to scientific explanations, and some genre characteristics of students' explanations. The findings suggested students did not have a clear definition of scientific explanations; however, students attached meanings such as exactness, truth and reality to scientific explanations. The students held an empiricist view of scientific explanations. Student explanations were primarily based on first-hand knowledge gained in the science laboratories. Most students did not give explanations based on a theory or principle and did not use deductive reasoning in their explanations. Students' explanations often included inferences from observations, evidence, and factual information. Students had difficulties in making causal explanations of biological phenomena particularly at molecular level. The language of students' explanations represented more of procedural accounts rather than theoretical and abstract accounts. Students' writings showed some of the genre characteristics

defined in literature, such as use of logico-semantic relationships. The lexical density values indicated that students' level of language is more complex than everyday speech, however, well below the level of scientists' language. The results of this research implied that school science curricula should emphasize explanations tasks that require students to use scientific theories and make causal connections. Science curricula should also explicitly address the different types of scientific discourses giving more emphasis to the discourses that have theoretical/abstract language.

INDEX WORDS: Scientific explanations, Biological explanations, Science laboratories, Writing to learn science, Student learning.

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DEDICATION

To my parents, Fazilet & Halis Peker.

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CHAPTER 1

INTRODUCTION

Background and Rationale

Study of explanations has been an area of interest for scholars from different fields. Philosophers of science, cognitive scientists, linguists, and rhetoricians have studied different aspects of explanations. Science educators have also become interested in scientific explanations in the context of teaching and learning science. This qualitative study focused on high school students' written explanations that are constructed during science laboratory investigations.

Contemporary notions of science education highly praise the teaching practices that promote inquiry-based learning, critical thinking and construction of knowledge (National Research Council [NRC], 2000). Within these notions, students are expected to act like scientists, understand the method and the nature of science, and practice these understandings in different science subjects and topics.

One current theme of science education is scientific literacy (Hand, Prain, Lawrence, & Yore, 1999). Providing a reasonable explanation and its communication in written context are two facets of scientific literacy and scientific thinking. Hand et al. (1999) contended that current views on scientific literacy emphasize the centrality of communication skills. Writing tasks in classrooms are important to provide opportunities to enhance communication skills of the students. Current views on scientific literacy also include an understanding of scientific processes and expect science learners, who are active constructors of knowledge, to develop

effective argumentation and to make connections among claims, evidence, warrants, and provide explanations (Hand et al., 1999; Hurd, 1998; Laugksch, 2000).

Referring to Brickhouse and Stanley's (1993, p.372) contentions about how "science teaching might best be constructed," if students are to understand science as a construction of persuasive explanations about the natural world, Hand et al. (1999) made a connection between explanation and writing tasks:

If students are to understand science as the construction of persuasive but ultimately provisional explanations of the natural world, then they need to tackle writing tasks that enable them to understand and practice this kind of inquiry, its procedures and basis.

Students will also need to learn from tackling this writing the basis on which scientific explanation are considered convincing by the scientific community (p.1024).

Explanations are very important in a scientific process, as one philosopher defines explanation as the end of the scientific inquiry. It is accepted that scientific theories are evaluated on the basis of their explanatory power (Schwitzgebel, 1999). For many, explanations are one of the primary goals of scientific enterprise (Hempel, 1993). A good explanation is a good indicator of understanding the phenomenon or the situation explained (Chi, Leeuw, Chiu, & Lavancher, 1994). Explanations can be considered as theory articulations, which refer to the connection between the observations and theoretical knowledge (Ohlsson, 2002).

The national Research Council emphasizes three essential inquiry skills that include explanations: "a) learner formulates explanation from evidence b) learner connects explanations to scientific knowledge and c) learner communicates and justifies scientific explanations" (NRC, 2000, p.29).

Researchers in science education and cognitive science studied different aspects of scientific explanations, such as type of student explanations (Tamir & Zohar, 1991), epistemological aspects (Sandoval, 2003) and cognitive aspects (Krupa, Selman, & Jaquette, 1985; Metz, 1991; Southerland, Abrams, Cummins, & Anzelmo, 2001) of students' explanations. Some researchers were also interested in the language aspect of students' explanations (Chambliss, Christenson, & Parker, 2003; Solomon, 1986).

The research related to the cognitive aspect of student learning suggested that the ability to make a scientific explanation is highly associated with the level of cognitive development of students (Krupa et al., 1985). Research in science education also revealed that there is a developmental pattern in students' explanations (Metz, 1991; Driver, Leach, Millar and Scott, 1996). Young students have difficulties in making explanations that are based on scientific theory and models. These students tend to explain scientific phenomena at a more descriptive level, with limited ability to identify different variables and causes. The research in cognitive science also confirms that students who provide self-explanations significantly increase their understanding of a topic (Chi et al., 1994).

Researchers in the field of writing to learn emphasized the role of writing in achieving the goals of scientific literacy (Glynn & Muth, 1994; Hand et al., 1999). The research in this field, in general, supported the view that writing is a very powerful learning tool. Researchers found that writing promotes conceptual change (Fellows, 1994), improves reasoning skills and generating new knowledge (Keys, 1994), and helps students in organizing ideas into coherent structures (Rivard & Straw, 2000).

Although much research has been conducted in the writing to learn science field (Rivard, 1994), there are still gaps in the literature. The biggest gap is the role of writing in laboratory

activities. In particular, students' involvement in scientific processes, such as making claims, generating evidence and constructing explanations have not been studied thoroughly (Keys, 1999; Wallace, 2002). The research that specifically investigates the students' scientific explanations constructed during laboratory investigations is very limited. Therefore, this study aimed to eliminate some of those deficiencies in the research related to scientific explanations and writing in the science laboratories.

Theoretical Perspectives

In this section, I will present two theoretical perspectives that guided my research study: a social constructivist perspective on student learning and a sociocognitive perspective on genre. Central to both of these perspectives are the paramount roles of social interaction and language in the processes of learning, meaning making, and communicating. Even though they will be discussed separately, these two perspectives complement each other. While student learning is approached by a social constructivist perspective, the student outcomes examined in this study, scientific explanations, are accepted as a genre which is approached by a sociocognitive perspective.

Social Constructivism

The roots of social constructivism can be found in the history of sociology, particularly in the sociology of knowledge and sociology of science. Marx, Mannheim and Durkheim are three important scholars who emphasized how society shaped individual beliefs (Kukla, 2000). For many in the field of education, Vygotsky is known to be one whose ideas greatly shaped social constructivism in education. For Vygotsky (1978), social environment was very critical in the learning process. He thought that social environment influences learning through different tools, such as social institutions (church or school), language, and cultural objects (e.g., machines)

(Schunk, 1991). In social constructivism, the focus is collective generation of meaning making through language and social elements, whereas radical constructivism is focused on meaning making at the individual level. Social constructivism assumes that meaning is made through language, and social interchange is a primary vehicle in knowledge creation and legitimization (Bredo, 2000; Lemke, 1990).

According to Gergen (1985, as cited in Schwandt, 1994) in the social constructionist approach “the terms by which the world is understood are social artifacts, products of historically situated interchanges among people” (p.127). In Gergen’s (1995) account of the social construction of knowledge, there are three basic points. First, “meaning is achieved through social interdependence” (p.24). Since meanings are recognized through communication, there must be at least two or more people to attain a meaning. As social interdependence is crucial in construction of meanings, social constructivism often emphasizes ideas like negotiation, cooperation, conflict, rhetoric, ritual, roles and social scenarios. Gergen’s second point is that meaning in the language is context dependent. Agreements between persons on the relationships of language to referents are reached within particular sociohistorical contexts. When contexts are changed, meanings made within those contexts can also be changed, even though referents remain same.

The third point from Gergen (1995) as to social construction of knowledge is that “language primarily serves for communal functions” (p.26). According to Gergen, language does not reflect an independent, objective world. Language carries out our actions within a game. Following an analogy between a language and a game, Gergen further asserts that there are socially established rules of a game, and there is not a “pure” language; all language is “applied in the sense that it carries out specific functions within some community” (p.27). Gergen gives

chemical descriptions of elements as an example to illustrate his point. All descriptive statements about elements are not picture of the real world, but special referents within the scientific community to make sense of the elements.

The current practices of social constructivism in science education focus on the use of language in classrooms, ideas of apprenticeship and enculturation, learning in groups, and scaffolding (Brown and Palinscar, 1989; Herrenkohl, Palinscar, DeWater, & Kawasaki, 1999; Hodson, 1999; Roth, 1995). A social constructivist perspective accepts that students have previous understandings that they bring into the classroom; through the social interactions these understandings are continually modified in order to achieve the desired outcomes. One of the important ideas in social constructivist tradition is that Vygotsky's (1978) notion of *zone of proximal development* which is "the distance between the actual development level as determined by the independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (p. 86). The idea of zone of proximal development provides a good model for learning in groups and ideas of apprenticeship (Brown & Palinscar 1989; Roth, 1995).

Relevance to the current study. Science learners are exposed to a common shared culture of science with a specialized language. Any developing scientific skill or ability in learners is, therefore, affected by the exposed culture and language of science. For instance, the ways that students construct scientific explanations are influenced by what is accepted as scientific explanations in their particular learning community. Moreover, when explanations are requested in written form, students also have to comply with the accepted forms of scientific communication. Writing itself is also a constructive process, which "promotes personal meaning making in relation to scientific explanations" (Hand et al., 1999, p. 1028). It is accepted that

language does not only describe or reflect preexisting concepts, but language actively creates those structures (Keys, 1999). In the current study, students conducted their investigations within groups. Although the effects of group learning for individuals were not studied, previous research indicated that group work or cooperative learning environments can improve individual learning (Brown & Palinscar, 1989; Roth, 1995). I presume that interactions that students made during the lab investigations might have affected their thinking and so their explanations. Even though students wrote their explanations individually, to some degree the scientific understandings they represent in their explanations were influenced by group work.

Sociocognitive Perspective on Genre

Communicating in disciplines, generating and sharing meanings happen through specific genres. Bakhtin (1986) defines genres as “typical forms of utterances” (p.63). An explanation has been recognized as a distinct discursive activity and genre (Connors, 1985; Rowan, 1988). The main purpose of explanatory discourse is informing rather than persuading or arguing (Connors, 1985). Rowan (1988) defines explanatory writing as “a discourse primarily designed to promote understanding by lay readers of some phenomena” (p. 29). Halliday and Martin (1993) characterize the genre of scientific explanations with two qualities: a) extensive use of action verbs and descriptive elements, and b) presentation of a logical order of the actions.

Accepting scientific explanations as a unique genre, I will adopt a sociocognitive perspective on genre proposed by Berkenkotter & Huckin (1993), which basically emphasizes the knowledge construction, meaning making, and communicating this knowledge and meaning through genre structures. Berkenkotter and Huckin indicated that the sociocognitive perspective on genre they developed was influenced by the following theories and ideas: structuration theory in sociology, rhetorical studies, interpretive anthropology, ethnomethodology, Bakhtin’s theory

of speech genres, Vygotsky's theory of ontogenesis and Russian activity theory, and what is called in American psychology as "situated or everyday cognition."

Berkenkotter and Huckin (1993) named five principles that shape a genre theory. In the following sections I will briefly present these principles. The first principle of sociocognitive approach to genre is "genres are dynamic rhetorical forms" (p.478). Although a genre develops as a response to recurring situations, and as learners' sociocognitive needs change, the genre used by learners also changes. Science learners develop their understanding of explanation genre, for example, by the recurring tasks that demands communication of explanations. This process can be considered as appropriation process of explanatory genre.

The second principle of sociocognitive perspective to genre is that genres are situated in their communicative places. Thus, students' explanations are situated in the context of science laboratory investigation in the current study. Bakhtin (1986) distinguishes two forms of genre, primary and secondary. Primary genre is performed in our daily life communications (e.g. informal talks, discourse related to mundane activities). Secondary genre is, on the other hand, a more complex and developed form of genre. This type of genre is often seen in the written communication of the members of an organized culture, such as science or literature. Referring to Brown, Collins and Duguid's (1989) work on situated cognition, Berkenkotter and Huckin (1993) consider genre knowledge of an academic practice as a form of situated cognition because that knowledge is "inextricably a product of the activity and situations in which it is produced" (p.485).

The third principle by Berkenkotter and Huckin on genre is that genre knowledge has both a form and a content component in it. When this principle is applied to the current research,

it means that students need to have an understanding of both the explanatory genre and understanding of the topic or phenomena in order to give good explanations.

Duality of structure is the fourth principle by Berkenkotter and Huckin (1993). They define this principle as follows: “As we draw on genre rules to engage in professional activities, we constitute social structures (in professional, institutional and organizational contexts) and simultaneously reproduce these structures” (p.478). So, duality of structure suggests a reciprocal relation between the parts of duality such as student and class (society). When students are engaged in laboratory activities, their use of genre structures during and after the lab activity reproduces the school science culture, as much as school science culture enculturates their understanding of scientific practice.

The last principle is community ownership, which refers to the idea that genres represent the norms, rules, ideologies and epistemologies of a discourse community. For instance, a student’s science laboratory report reflects the accepted scientific understanding in that student’s discursive community (Berkenkotter & Huckin, 1993).

To summarize, accepting scientific explanations as a unique genre, and school science culture as an institution that mediates the shared meaning of explanation among learners, a social constructivist theory of learning informs the current research. Both social constructivism and sociocognitive perspective agree that the act of learning is greatly influenced by social interaction and language.

Purpose and Research Questions

The value of providing an explanation as a component of the scientific inquiry process, and, therefore, as a goal of scientific literacy has been articulated in the previous sections. Constructing an explanation requires students to make connections among the preceding steps of

the inquiry such as observation, hypothesis testing, claiming and so forth, as well as the interpreted data, and accompanying theories or knowledge bodies. The act of explaining is a cognitively complex task and it requires some science process skills and relevant content knowledge that are defined and described in science education reform documents (NRC, 2000).

Writing as a knowledge-transforming model (Bereiter & Scardamalia, 1987), which includes an interaction of content knowledge and discursive knowledge, offers one of the best ways to stimulate student thinking and reasoning. As a naturally constructive process, writing in science helps students to develop their personal understanding of the outside world, yet it requires a formal presentation of justified ideas. Writing in science assists developing their argumentation skills and logical presentation of ideas, which are preconditions of generating a satisfactory scientific explanation.

The purpose of the current research was to examine high school biology students' explanations in written context. Particularly, students' explanations were examined for the types of reasoning involved, the source of knowledge used to construct an explanation, and common patterns in their explanations. The following questions guided the research study:

- 1) What are students' meanings of scientific explanations?
- 2) What are the characteristics of high school students' scientific explanations?
- 3) What is the nature of students' epistemologies related to scientific explanations? (E.g. source knowledge or evidence drawn upon to provide an explanation)
- 4) To what degree do students' explanations represent the characteristics of explanation genre identified in the literature?

Brief Overview of the Study

This qualitative interpretive study examined high school biology students' scientific explanations in terms of the meanings students attribute to scientific explanations, students' epistemologies related to the scientific explanations and the characteristics of students' explanations. Some linguistic aspects of students' explanations were also examined. Data sources included students written explanations on the lab sheets and science letter writing activities, individual interviews and classroom observation. Participants were 16 tenth grade high school students from two different class periods taught by the same teacher. The data was collected during six different science laboratory investigations. In the following chapters, a review of the relevant research, detailed data collection and analysis techniques, findings of the study, and a discussion and implications of the study are provided.

CHAPTER 2

LITERATURE REVIEW

Providing scientific explanations and communicating them through writing are two important components of scientific literacy (Hand et al., 1999). Both construction of a satisfactory explanation and effective writing requires one to organize the ideas logically and make connections among the pieces of information. This chapter reviews the literature related to writing to learn science and scientific explanations. The chapter is organized under four main sections of review: writing to learn in general, writing to learn in science, scientific explanations, and research on students' scientific explanations. The review of literature on writing to learn in general shows the relationship between writing and thinking and presents models of writing. The review section of writing to learn in science presents empirical research in the field of science education as related to writing to learn. The third main section of literature review is on scientific explanations, which discusses various types of explanations and presents different accounts of explanations from philosophical and linguistic perspectives. The last main section of this chapter presents the research on students' scientific explanations conducted by science educators and cognitive scientists.

Writing to Learn in General

Role of Writing in Learning

Several major points about the relationship between writing and learning will be presented from the literature. These are the association between writing and reasoning (Applebee 1984), writing is cognitively more stimulating than reading (Langer & Applebee, 1987, Rivard,

1994), writing is a unique form of learning (Keys, 1994,) and writing involves metacognitive processes (Glynn & Muth, 1994).

Writing in general is highly associated with thinking and reasoning. Applebee (1984) named four factors that link writing to thinking:

(a) permanence of the written word, allowing the writer rethink and revise over an extended period; (b) the explicitness required in writing, if meaning is to remain constant beyond the context in which it was originally written; (c) the resources provided by the conventional forms of discourse for organizing and thinking through new ideas or experiences and for explicating the relationships among them; and (d) the active nature of writing, providing a medium for exploring implications entailed within otherwise unexamined assumptions (p. 577).

As Applebee's lists suggest, writing is a purposeful activity, which requires one to organize ideas in relation to the specific goals.

There is evidence in the literature that writing is cognitively more stimulating than reading. Langer's (1986 as cited in Rivard, 1994) research indicated that children appear to be more aware of their use of strategies, rhetorical structures, and background knowledge while reading than while writing. Langer and Applebee's (1987) research that compared the effects of limited writing opportunities (note taking and answering study questions) and extensive writing opportunities (writing summaries or analytic essays) on students' learning and thinking showed that with limited writing, students focus on larger chunks of information superficially, whereas students who wrote essays appeared to integrate the information with an engagement in more complex thinking processes.

In her review of the literature, Keys (1994) argued that the following ideas support the belief that writing is a unique form of learning:

- (a) writing employs three forms of representations at one time, enactive (hand), iconic (eye), and symbolic (brain); (b) writing is necessarily engaged, committed, and personal;
- (c) the permanence of written texts allows for rescan and reformulation of knowledge and
- (d) writing provides practice in using language that represents specific scientific ideas (p. 1004).

Formal writing requires one to have a complete and warranted understanding to communicate with the public (Keys, 1999). Furthermore, it is suggested that writing is also related to metacognitive processes. Students who are competent in writing can retrieve information from long-term memory. This retrieval process requires some skills associated with metacognition, idea construction, idea relation, text production and revision (Glynn & Muth, 1994).

Halliday (1993) argued “writing brings language to consciousness; and in the same process it changes its semiotic mode from the dynamic to the synoptic, from flow to stasis, from choreographic to crystalline, from syntactic intricacy to lexical density” (p. 118). This crystallization of language allows the writer to discover what it is he or she knows.

Santa & Havens (1991) noted that writing encourages active involvement of students in the learning process. They contended that students usually tend to be passive, waiting for teachers’ actions, and therefore writing is appropriately a good stimulator for students to learn actively. Santa & Havens also indicated that writing demands organization of ideas, thus making writers cluster information and hierarchies of ideas more easily. In addition, Santa and Havens addressed the relationship between writing and metacognitive skills. They made the point that

understanding is crucial for good writing; one cannot write about something unless he/she understands it.

Models for Writing to Learn

There are different models and theories which explain how learning or discovery occurs through writing. In this section I will briefly present some of these models or positions as to how learning occurs through writing. First, I will summarize two positions related to the nature of discovery through learning discussed by Galbraith (1992). Then, I will present models of writing introduced by Bereiter and Scardamalia (1987). Finally, I will discuss the different hypotheses as to the nature of learning through writing from Klein's (1999) review paper.

Galbraith (1992) discussed two different positions regarding discovery through learning: the classical position and the romantic position. In the classical position, discovery is accepted as a result of planned rhetorical organization, whereas the romantic position accepts the discovery as "a consequence of the spontaneous spelling-out of ideas in continuous prose"(p. 45). Galbraith's experimental research supports the romantic position.

Bereiter and Scardamalia (1987) also presented two models of writing to learn: knowledge telling and knowledge transforming. The knowledge-telling model refers to generating content for discourse in written text. It is more appropriate for routine tasks and it does not foster generating new knowledge, since it deals with pre-established language structures and contents. Basic steps of the knowledge-telling model of composing include the mental representation of a writing task, the generation of topic identifiers, and the use of these topic identifiers as cues to retrieve information through a process of spreading activation. In the knowledge-telling model, knowledge about the topic is presented without the use of external information and interaction between the content space and discourse space. The writer often

reports a personal experience and “relies on already existing discourse production skills in making use of external cues and cues generated from language production itself” (p. 9).

On the contrary, the knowledge-transforming model of writing has potential to increase knowledge acquisition through content processing and discourse processing actions. The knowledge-transforming model is a dynamic reciprocal interaction of content knowledge and discourse knowledge domain. The content space part of the model includes the following processes: identification of relevant data, determination of meaning of data, construction of inferences and development of conceptual knowledge structures. Meanwhile, discourse domain (rhetorical space) deals with rhetorical encounters such as making language choices, communicating the meaning of data, constructing canons of argument, and developing knowledge of scientific genre and the nature of science. This rhetoric and content interaction leads to generation of new knowledge (Bereiter and Scardamalia, 1987). The knowledge-transforming model is accepted as a theory that fits well with constructivist learning theories, since it is reflective in nature (Keys, 2000).

Klein (1999) discussed the four main hypotheses as to the effect of writing on learning in his review of the literature. Those hypotheses are:

(1) writers spontaneously generate knowledge, (2) writers externalize ideas in text, then reread them to generate new inferences, (3) writers use genre structures to organize relationships among elements of text, and thereby elements of knowledge, and (4) writers set rhetorical goals, then solve content problems to achieve these goals (p.203).

Among those, use of genre structures has been the most accepted and supported hypothesis (Klein, 1999). Genre-based writing often has been interpreted as a cognitive strategy. Genre-based models focus on the structure of the text rather than on the process of composing.

Among the hypotheses listed above, genre-based models best suits the context of this study because explanations are accepted as a unique genre (Connors, 1985; Halliday & Martin, 1993; Rowan, 1988; Veal, 1997). Moreover, a genre-based model emphasizes structural organizations of the text which also help us to understand ways of thinking involved in the construction of explanations. For instance, identifying the kinds of logico-semantic relationships made within an explanation text tells us about the thinking involved in that explanation, such as causal thinking.

Writing to Learn in Science

The importance of writing to learn science has been articulated by many authors (Ambron, 1987; Holliday, Yore, & Alverman, 1994; Rivard, 1994; Hand et al., 1999). Hand et al. (1999) stated “writing in science can serve to engage students’ prior knowledge, facilitate exploration of alternative ideas or reveal new possibilities, consolidate new concepts into prior understanding or integrate divergent concepts, and assess understanding, reasoning and argumentation” (p.1028). It is assumed that writing helps the development of students’ communication skills, and assists students to make connections among different ideas.

There is literature that emphasizes the importance of writing in science to achieve scientific literacy goals (Glynn & Muth, 1994; Hand, Prain, Lawrence, & Yore, 1999). Hand et al. (1999) contend that writing in an interactive-constructivist science classroom has a great potential to enhance science learning and promote the personal knowledge making process. It is also an assertion of Hand et al. (1999) that “writing in science can serve to engage students’ prior knowledge, facilitate exploration of ideas or reveal new possibilities, consolidate new conceptions into prior understanding or integrate divergent concepts, and assess understanding, reasoning and argumentation” (p. 1028).

It has also been shown that writing can help the development of scientific reasoning such as selecting and processing textbook passages, drawing conclusions and formulating models, and comparing and contrasting the ideas (Keys, 1994). In her research, Keys used a collaborative report-writing intervention to investigate how ninth grade general science students use scientific reasoning in their laboratory reports. Students wrote ten laboratory reports over a 4.5-month period. The results of Keys's research showed that students used scientific reasoning skills for several different purposes such as to assess their current models of scientific understanding, make observations, interpret the meaning of results, and generate new models based on their data and relevant information. Keys's research suggested that science writing improves students' skills and abilities to make links among the concepts, claims, warrants, evidences (Keys, 1994), especially when the writing task requires students to be comprehensive in their writing and include basic elements of an inquiry process, such as hypothesis, data, interpretation, evidence, etc. In a similar vein, another study of Keys (1995) revealed that as a result of collaborative writing, students became able to assess their prior models of scientific phenomena, generate new models and extend models to new situations. She used the same type of method as in her previous study (Keys, 1994).

It is believed that writing in science can promote conceptual change. Fellows (1994), in her study with 25 middle school students, used concept maps to understand the role of writing. She reported that students added new concepts and principles to their schema, and also students better organized their knowledge and accepted scientific understanding after writing over a 12-week science unit.

Rivard and Straw (2000) studied the effect of talk and writing on learning science among 43 eighth grade students in his quasi-experimental study. In the study, students were randomly

assigned to three groups: talk-only, writing-only, and talking-writing combined. Students in each group were given tasks that involve construction of scientific explanations for real- world ecological problems. Their results related to writing suggested that analytical writing is important for organizing ideas into coherent responses.

Research on the Science Writing Heuristic. In this section, I will present some of the research particularly related to the Science Writing Heuristic (SWH), since this study included SWH intervention. Keys, Hand, Prain and Collins (1999) define SWH as “representing a bridge between traditional laboratory reports and types of writing that promotes personal construction of meaning” (p. 1065). SWH includes two basic stages. First, a teacher-guided and -designed activity is introduced to students prior to experiment. Then, a student-driven, inquiry-promoting template is applied. The first step helps students to clarify their prior understandings, and the second step helps students to make connections between their observations, investigations, evidence and claims.

Wallace & Hand (2004) indicated that SWH promotes students’ conceptual and metacognitive understandings. They pointed out four distinct features of SWH compared to a conventional laboratory report: a) use of writing, before, during and after laboratory activity; b) emphasis on the collaborative nature of scientific work, such as the negotiation of meaning; c) encouragement to make connections among the different elements of the inquiry investigation, i.e., observation, data, claim, evidence; and d) reflection on personal knowledge growth.

Research suggests that SWH promotes students’ metacognitive skills and self-understandings; SWH also enables students to extend, elaborate, and enhance their science ideas. For example, in their interpretive research, Keys et al. (1999) worked with two classes of eighth grade students. The intervention of SWH in secondary school grades showed that SWH

promoted students' metacognitive skills and self-understandings. It was also concomitant with the use of SWH that students attribute meaning to their scientific data. Furthermore, Keys et al. (1999) found that SWH enabled students to extend, elaborate, and enhance their science ideas.

Keys, Hand, & Yang's (2001) study indicated that students found SWH useful in the following ways: framing their own research question, participating in peer group discussions, making connections between concepts, and writing. Keys et al. also found that SWH helped students to develop a sophisticated understanding of the nature of science. Wallace's (2002) research that uses the intervention of SHW indicates that students tend to use the sources of knowledge that closely match their epistemologies for their scientific explanations. These sources were first hand observations, textbook information, or a blend of all possible sources.

Summary for writing to learn. The review of literature in this field suggested that there is an agreement among the researchers that writing is a very helpful strategy to improve science learning. A number of mental models have been articulated by different researchers to show that writing and thinking are highly associated (Bereiter & Scardamalia, 1987; Galbraith, 1992). The empirical research in this field has confirmed that writing tasks in science classrooms assist students to improve their reasoning and scientific thinking skills, and also they help students to organize and present ideas in more coherent manner (Fellows, 1994; Keys, et al., 1999; Keys, 1995; Rivard, 1994; Rivard & Straw, 2000). Although there is much research conducted in the writing to learn field (Rivard, 1994), there are still gaps in the literature. The biggest gap is the role of writing in laboratory activities. Specifically, students' involvement in scientific process, such as making claims and generating evidence and explanations, has not been studied thoroughly (Keys, 1999). The current research study, therefore, aimed to look at students' explanations constructed as a response to science laboratory activities.

Scientific Explanations

One of the central goals of the scientific enterprise is to explain the natural world. Scientists seek to explain both the physical and biological worlds in which we live. In this sense, scientific explanation is highly associated with scientific understanding. We understand the natural world, to the extent that we explain that world. Therefore, explanations have two important values. First, explanations provide us with a unified picture of how various phenomena in the world fit together. Second, through explanations we understand how things work in the world (Salmon, 1998). While the former refers to the unification idea in natural sciences (Kitcher, 1997), the latter refers to causal/mechanistic view of the world (Salmon, 1998).

The importance and value of providing an explanation is not less important in school science than in real science. “To formulate and revise scientific explanations” are among the “fundamental abilities necessary to do scientific inquiry” (NRC, 2000, p.19). According to National Research Council (2000), “scientific explanations are based on reason.” Explanations “provide causes for effects and establish relationships based on evidence and logical argument” (p. 26).

Before considering different views of explanations, it is important to point out that the word explanation is ambiguous. The term explanation is used loosely in some contexts. For instance, an explanation may be taken for a description: “Explain the term osmosis” or “Explain the term codominance.” Although the commands above ask one to explain the concepts, what is actually being asked for is a description or a definition of those concepts (Horwood, 1988). Quoting Bateson’s (1979) work, Horwood (1988, p. 41) provides us with the simple difference between an explanation and a description, “Description is purely information and the bits of

information are isolated from any network of relatedness. An explanation is given when connections are drawn between and among the pieces of information.”

Ohlsson (2002) expressed a similar opinion, and contended that explanations specify the manner of how generative relationships works together, while description merely names these generative relationships. A more detailed account of Ohlsson’s ideas in this regard is discussed later.

The type or the functions of explanations have also been a focus of interest. Martin (1972) pointed out that explanations in science and science education can refer to five different things: “1) clarification of words or phrases, 2) justification of beliefs or actions, 3) causal accounts of events, states, or processes, 4) theoretical derivations of laws and 5) functional accounts of organs (e.g., heart, kidney, etc.) or social institutions” (p.45).

As seen in Martin’s categorization of explanation, we have a wide range of situations where explanations play a role. However, number three and four are of most interest in science education, because those two require scientific reasoning, science content knowledge, and logical thinking. Functional explanation is also widely used in biology. Although functional explanations can be useful in many situations, they may lack causal connections, and may not necessarily provide an adequate scientific explanation.

Gilbert, Boulter, & Rutherford (1998) argued that explanations, in the simplest form, are answers to the specific questions. They pointed out that life scientists in their work look for answers for specific questions rather than try to validate a theory. Gilbert et al. raised five questions whose answers yield an explanation: “Why is the inquiry to be carried out?; How does the phenomenon behave? ; Of what is the phenomenon composed?; Why does the phenomenon behave as it does?; and How might it behave under other conditions?” (p.85-87).

The first question deals with our intentions of choosing a particular phenomenon to study. An answer to the second question requires a descriptive account of how a phenomenon behaves under certain conditions. The third question addresses the units of a phenomenon. An answer to this question gives an interpretation of phenomenon's physical structure. The fourth question focuses on the causal relationships; the phenomenon is explained through some casual mechanisms. Finally, once the phenomenon is explained in current conditions, the next question focuses on how the phenomenon behaves under different conditions. Based on the answers to the above questions, Gilbert et al. provided a typology of explanations (1998), which included five different types explanations: "(1) intentional explanation, (2) descriptive explanation, (3) interpretive explanation, (4) causal explanation, and (5) predictive explanation" (p.87).

Explanation as a Genre

Dissemination and communication of scientific knowledge entails the use of certain genre structures. Within these genre structures, *explanation* is a unique science genre. A definition of genre given by Martin (1984, as cited in Eggins, 1994) is that: "a genre is a staged, goal-oriented, purposeful activity in which speakers engage as members of our culture" (p.26). Halliday & Martin (1993) indicated two distinct features of explanations: "(a) explanations have a higher percentage of action verbs; and (b) the actions are organized in a logical sequence" (p. 191).

The definition of explanatory discourse has been an issue of debate (Rowan, 1988). As Rowan noted there are two goal-emphasizing definitions of explanations. According to one definition given by Connors (1985), explanatory discourse is the act of providing pure information and persuasion is not purpose. On the other hand, Martin's (1970 as cited in Rowan, 1988) definition of explanatory discourse highlights two different types of explanatory acts:

explaining as research or inquiry and explaining as teaching. While the former purposes to find an answer to a scholarly question, the latter purposes to help lay audience understand something already known (Rowan, 1988).

Rowan (1988) briefly defined explanatory writing as a “discourse primarily designed to promote understanding by lay readers of some phenomenon” (p.29). Rowan identified three subtypes of explanations: 1) language oriented (elucidating explanations), 2) reality oriented (quasi-scientific explanations), and 3) reader oriented (transformative explanations). Language oriented or elucidating explanations aim to improve one’s understanding of a meaning of a term and its use. This type of explanation is often confused with description. The distinction between a description and an explanation has been discussed in the review of science education literature (Horwood, 1988). Quasi- scientific explanations are the type of explanations that are more of an interest in this study. Rowan (1988) observed, “quasi-scientific explanations are designed to overcome difficulty in seeing how a group of propositions cohere to form a meaningful representation or picture of reality” (p.36). Since quasi-scientific explanations serve many fields of study for what scientific explanations serve for scientists, it is called quasi-scientific. Finally, transformative explanations refer to “explanations that are designed to overcome readers’ difficulties in rejecting and supplanting their own plausible, but erroneous, theories of familiar events in the everyday world” (p.37). For instance, explanation of why the sky is blue. In order to understand this type of explanation, one needs to transform implicit theories to more explicit ones.

Veel (1997) identified six different explanation types that are seen in school science texts. These are, sequential explanations, causal explanations, theoretical explanations, factorial explanations, consequential explanations, and explorations. Each of these types of explanations

serves a special purpose in our scientific communication. Table 2.1 shows these six types of explanations and their social purposes.

Table 2.1

Explanation genres and their social purposes according to Veel (1997, p.172)

Genre	Social Purpose
Sequential explanation	To explain how something occurs or is produced- usually observable sequences of activities which take place on a regular basis
Causal explanation	To explain why and abstract and/or not readily observable process occurs
Factorial explanation	To explain events for which there are a number of simultaneously occurring causes
Theoretical explanation	To introduce and illustrate a theoretical principle and/or explain events which are counter intuitive
Consequential explanation	To explain events have a number of simultaneously occurring effects
Exploration	To account for events for which there are two or more viable explanations

Veel (1997) noted that from his experience with teachers, teachers value causal explanations more than sequential type of explanations since these teachers believed that casual explanations present more evidence of students' development.

Veel contended that there are significant shifts among the different types of scientific genres during science lessons depending upon the focus of activities. As focuses change, a shift occurs between their associated forms of genres, for instance, a shift from procedures and procedural recounts to explanations. When students are asked to report a procedural event which took place in a specified time, place and other defined conditions, their reports include information that resides in their first-hand experience. However, when an explanation of a phenomenon that can be generalized is demanded, the information required to render an explanation is not readily available in students' first-hand experience. Therefore, a fundamental shift takes place from one genre to another.

When students move to higher grades, the nature of classroom tasks also shifts from ones that require procedural accounts to ones that emphasize more of a theoretical knowledge or book knowledge privileging the mainstream understanding of science. Veel (1997) calls this a change from “knowing by doing” to “knowing by reading” (p.175).

Veel’s categorization of scientific explanations offers a good framework for the current study. Since the written data was collected through different science laboratory units, the nature of explanations tasks varied in each unit. Veel’s framework has been very helpful to distinguish different types of explanations observed in the current study. A more detailed discussion of Veel’s account of explanatory genres is provided in the findings chapter.

Notions of apprenticeship and epistemological appropriation

In this section notions of apprenticeship and epistemological appropriation will be briefly discussed. When we accept scientific explanations as genre and social constructivism as a guiding learning theory in science education, we also accept that students adopt and appropriate explanatory genre within scientific discourses. Therefore, a consideration of these notions will be helpful for us framing students’ scientific explanations as social activities within particular communities (i.e. science laboratories).

The notion of apprenticeship has been presented by many social psychologists to explain learning of implicit rules or unspecified skills (e.g., Hung, 1999), for instance, students’ development of scientific discourse. Students were not typically taught about the rules and customs of scientific discourse. However, students understand the nature of scientific discourse as they are exposed to scientific texts and asked to communicate through writing laboratory reports or through group discussions. Interaction involved in learning and situated conditions of

learning are integral parts of learning process. As Hung (1999) quoted from Polanyi, learning many times happens through examples:

You follow your master because you trust his manner of doing things when you cannot analyze and account in details for its effectiveness. By watching the master and emulating his efforts in the presence of his example, the apprentice unconsciously picks up the rules of the art, including those which are not explicitly known to the master himself. These hidden rules can be assimilated only by a person who surrenders himself to that extent uncritically to the imitation of another (p.197).

In the context of the current study, students were not explicitly taught about constructing explanations. However, use of the SWH, teacher's and researcher's dialog with students, and demonstrations of examples scaffolded their thinking. When students are involved in writing tasks that require them to use certain type of expressions and language structures, such as explaining or providing evidence, they are also involved in an apprenticeship process into scientific discourse (Veel, 1997). Learning science involves learning of scientific language, which is not simply the learning of scientific terms and jargon, but appropriating the language of science and developing the ability of constructing personal meanings with the use of language.

Another important notion is appropriation. Both the language and the epistemology of science are appropriated by learners. Bakhtin (2002) described the appropriation of language as following:

Prior to this moment of appropriation, the word does not exist in a neutral and impersonal language...but rather it exists in other people's mouths, in other people's contexts, serving other people's intentions: it is from there that one must take the word, and make it one's own (p.293-294).

In order for students to construct scientific knowledge, they need to internalize the language of science. This internalization requires the understanding of the symbols used by others to create meaning. When the language is appropriated, new meanings can be created by learner and new understandings can be grasped.

Before looking at a model of epistemological appropriation, I will provide a short review of research on students' epistemologies. Researchers have proposed different models of students' epistemologies. In Carey and Smith's (1993) model, they proposed three levels of students epistemologies related to students' understandings of the nature of science. At level 1, students do not make a distinction between scientists' ideas and actions. At this level, students perceive science as a discovery process, in which scientists try out things. At level 2, students can make the distinction between an idea and an experiment. Students understand that experiments are conducted to find an answer to a specific question, rather than just randomly trying out. At level 3, students not only understand the purpose of an experiment, but also realize that scientific theories, explanations, and predictions are involved in the process of science.

Another model of students' epistemologies of scientific reasoning was that proposed by Driver et al. (1996). This model is introduced in more detail in the review of research in scientific explanations. Briefly, their model includes three stages. At the most primary level, phenomena based-reasoning, students' reasoning is limited to their observations. At the second level, relation-based reasoning, students reasoning can distinguish different factors involved in a phenomenal outcome, and they can identify the relations among these factors or variables. At the most sophisticated level, model-based reasoning, students can evaluate a scientific model or theory; they can realize the fallacies between a theoretical assumption and natural reality.

Combining what is known about students' epistemologies and notion of appropriation, an epistemological appropriation can be identified. Drawing upon Polanyi's work, Hung (1999) discussed students' epistemological appropriation. Hung identified three major levels of processes involved in epistemological appropriation: growing into dependency (submitting), dependency (mirroring) and growing out of dependency (constructing). Each of these major levels is represented by two stages in a continuous order. A total of six processes are involved in the epistemological appropriation. These processes are shown on Table 2.2.

Table 2.2

Processes in epistemological appropriation (Hung, 1999, p.201)

Growing into dependency (Submitting)	Dependency (Mirroring)	Growing out of dependency (Constructing)
1. Novices recognize the differences in their interpretive norms compared with the beliefs of the community.	3. Novices continue to mirror or imitate the strategies and approaches acquired from practitioner(s) through coaching.	5. Novices commit to constructing or experimenting, trying out his or her own ideas independently.
2. Novices self-regulate in order to submit to the structural supports and interpretations according to the beliefs and rules of the community.	4. Novices coconstruct meanings and actions with the practitioner(s), and together they engage in meaning negotiations.	6. Novices discover for themselves patterns, ideas, concepts, and beliefs inherent in the community.

Philosophical Views of Explanations

Explanations have long been discussed in philosophical circles, after Hempel and Openheim introduced the famous deductive-nomological (D-N) model in the late 1940s (Hempel, 1993). According to this model, explanations are simply logical argumentations. Before we look at D-N model in more detail, it will be useful to know about two terms used in the philosophy of explanations: explanandum and explanans. The former refers to whatever is being explained. An explanandum can be a phenomenon or an event. The latter refers to the specifying information about the explanandum. Explanans are typically laws and background conditions. So, using this new terminology, in the D-N model, an explanandum is determined by

explanans (i.e., the initial conditions and relevant laws). In this model, explanations are deductions derived from scientific laws based on the initial conditions. For example:

All metals conduct electricity	(Relevant law or theory)
Iron is a metal.	(Background facts or initial conditions)
Iron conducts electricity	(Explanandum)

As it can be noticed in the above example, in the context of the D-N explanations, laws are considered as simply universal generalizations. The D-N model was, later, expanded to cover probabilistic conditions. Inductive-statistical (I-S) explanation, for example, is similar to the D-N model, except, the explanandum is provided in terms of probability based on the laws, and initial conditions. Hempel's model has been criticized for many reasons, but those discussions are beyond the scope of this literature review.

Another account of explanation is the causal account of explanation (Salmon, 1998). In this account, explanations are not arguments and they do not necessarily involve laws. Salmon (1998) argued that events could be explained by showing how they fit into patterns of the physical world. Salmon indicates that explanatory models requiring logical (e.g. D-N model) and nomological necessities are deterministic models, and these models fail to explain some phenomenon, such as quantum physics. Therefore, Salmon contends that an explanatory model should be effective in both deterministic and indeterministic contexts.

One important view is van Fraassen's (1997) pragmatic approach to the scientific explanations. According to this view, explanations have a pragmatic value for the person who is explaining. Ladyman (2002, p.208) exemplifies this situation: "Suppose someone asks 'why did the dog bury the bone?' This might mean 'why did the dog, not some other animal bury the bone?', why did the dog bury, rather than eat the bone? , or perhaps why did the dog bury the

bone, but not a ball?” As seen in the example, what counts as an explanation in a particular case depends upon the person’s interest.

Mayer (1992), in his review of the philosophy of science, provided three distinct views of explanations: explanation as description of phenomenon, explanation as induction of rules, and explanation as invention of models (Table 2.3). In the first view, explanation is the statement of relationship between the observable events. Mayer used a pump example: “When you press down on the pump handle, air comes out of a hose”(p.229). In this example, while somebody describes the events, he or she also provides an answer to the question “why did air come out of the hose?” (p.229).

In the second view, explanation is provided with inductive reasoning, which is the use of individual facts to form a general idea or rule. So, in the pump example context, one can understand that there is a correlation between the amounts of power applied to the pump handle and the amount of the air come out of the hose. When you apply a little pressure to the handle, a little air comes out of the hose. When you apply more pressure, a greater amount of air comes out. From these observations, an induction can be made: The amount of air comes from the pump is proportional to amount of pushing down on the handle (Mayer, 1992).

The final view of explanation is the invention of models. Inventing models helps us to explain things that we cannot directly observe. Knowing certain principles and rules, without observation, we can explain some phenomena. For example, one can respond to the question “why did air come out of the hose” using a model understanding without any observation of that particular phenomena. The relevant principle says when air is squeezed, its pressure is increased. Therefore, when we push the handle, air pressure inside the pump is increased exerting a power to open the outlet valves, and air comes out.

Table 2.3

Three Views of scientific explanation (Mayer, 1992, p. 229)

<i>View</i>	<i>Input</i>	<i>Output</i>
Description of phenomena	Observation of events	Descriptions
Induction of rules	Description of relations among events	Rules
Invention of models	Descriptions and rules	Models

Summary for philosophical views of explanations. Philosophy of science provides us with alternative models and conceptualizations of scientific explanations. It contributes to our understanding of scientific explanations and expands our scopes of scientific explanations. In order to assess students' explanations and develop effective teaching strategies to improve students' explanations, it is important for the practitioners of science education to know about the nature of scientific explanations. For example, an explanation can be deterministic or indeterministic, it can be derived from laws, it can present a cause-effect relationship, it can be based on empirical data or it can be based on model or theories only.

Some of the philosophical models and views of explanations presented above are already used by science education researchers to examine students' explanations. For example, Zuzousky and Tamir (1999) used the D-N model to analyze students' explanations in physical science. There is also a study (Driver, et al., 1996) that is presented in the following sections which quite matches with Meyer's (1992) presentation of views of explanations.

Research on Students' Scientific Explanations

There have been different foci of the research on explanations in science education. One general purpose of research was to categorize the students' explanations based on different criteria. Some researchers were interested in the final form of the students' explanations, and

made their categorizations based on the type of explanations, such as anthropomorphic, teleological, causal, proximate, and ultimate causation (Tamir, 1985; Tamir & Zohar, 1991). Some researchers were interested in development of explanations; they studied the cognitive aspects of explanations, and their analysis offered cognitive frameworks (Metz, 1991, Ohlsson, 2002, & Southerland, Abrams, Cummins, & Anzelmo, 2001). Yet, others were interested in epistemological aspect of the explanations, and their analysis provided an epistemological framework (Driver et al., 1996).

So far, two types of explanations that are common among children and often used in biology have not been discussed. These are teleological and anthropomorphic explanations. Teleological explanations are considered goal-directed explanations, which explain the phenomena in reference to a purpose or a pre-determined end (Mayr, 1988). As Tamir & Zohar (1991) concluded from Hempel's work (1965), since teleological explanations are given in terms of purposes and intentions, they give us the feeling that we really understand the phenomenon. Tamir & Zohar (1991) argued that teleological explanations have pedagogical heuristic value because they help students to organize their facts and understand the phenomena better. On the contrary, Shellberg (2001) contended that teleological explanations are not scientifically satisfactory because "teleological thinking mixes up cause and effect, making it seems that the effect or supposed purpose is the cause" (p.16). Shellberg (2001) exemplifies this with the following question: "Why do snowshoe hares turn white?" (p.16). A teleological answer to this question would be "to be camouflaged." However, Shellberg (2001) points out that being camouflaged is the effect of turning white. The causal explanation of the question should refer to the control of pigment (melanin) production in response to decreasing daylight.

In anthropomorphic explanations, human characteristics or behaviors are attributed to other living things. For example, “Birds fly toward south, because they feel cold in the north and decide to go warm places.” The example gives the impression that the birds reason like humans.

There are also two types of biological explanations introduced by Mayr (1998): mechanistic proximate and mechanistic ultimate explanations. According to Mayr (1988) mechanistic proximate explanations refer to the immediate set of causes of the phenomena, and mechanistic ultimate explanations refer to the causes that have long biological history, such as natural selection or adaptation. Mayr clarifies these explanations using the example of bird migration. When we think about the causes of bird migration, there are some immediate causes such as physiological causes (i.e. photoperiodicity and the triggering effect of sudden temperature drop). Proximate explanations are based on those immediate causes. There are also causes of bird migration that rely upon history and genetic disposition. These causes are ultimate and they are part of the ultimate explanations.

Tamir (1985) studied whether students could distinguish between causal explanations and teleological formulations. Using statistical methods, he analyzed 1,905 high school biology students’ responses to teleological and non-teleological items that were given as part of a lengthy matriculation exam. The results of Tamir’s study indicated students’ ability to distinguish between teleological and causal explanations was correlated with comprehension of biology topics. For example, higher achieving students were better than lower achieving students in distinguishing between causal and teleological explanations. Tamir (1985) attributed students’ inabilities to make distinction between these type explanations to the students’ biological misconceptions.

Tamir & Zohar (1991) investigated high school students' reasoning related to providing anthropomorphic and teleological explanations. One purpose of their study was to understand whether students use anthropomorphic and teleological reasoning because of their confusion with the real causes or because of the convenience of those reasoning. They interviewed 28 students presented with a series of anthropomorphic and teleological statements and asked students whether the statements could be a part of a biology textbook or not, and asked a reason for the answer. They found that the students tend to believe anthropomorphic formulations more when the statements were about animals than those related to plants. Tamir & Zohar's (1991) findings suggest that students support anthropomorphic formulations because anthropomorphic statements "make concepts and processes more comprehensible to students" (p.65). Furthermore, those statements do not necessarily imply that anthropomorphic reasoning is prevalent in students' reasoning.

Zuzousky & Tamir (1999) examined fourth and eight grade students' scientific explanations. Their interest was to assess scientific explanations across three different content areas: earth science, life science and physical science. Zuzousky & Tamir used data from the Third International Mathematics and Science Study. These included multiple-choice items, short answer questions, and some open-ended questions. Different from the research presented above, in their analysis Zuzousky and Tamir (1991) used D-N model to assess students' explanations. For example, one of the questions asked to students in the earth science areas was, "why do the sun and the moon look the same size?" (p.1111). The relevant rule (law) to answer this question in a D-N model of explanations was similar to "The more distant an object, the smaller it appears to us" (p.1112). Thirty percent of the students, in their study used a relevant rule to give their explanations. In their analysis of the 2,351 fourth grade and 1,377 eighth grade students,

Zuzousky and Tamir (1991) found that in both age groups many of the students' explanations were incomplete. For instance, students did not mention the antecedent conditions, or relevant rules. They also found that students rarely used scientific terms, instead using descriptions and teleological explanations.

In order to make a reasonable explanation, one should have a basic understanding of the subject matter to be explained. Otherwise, explanations would not be more than unwarranted speculations. In this respect, the nature of an explanation is highly associated with understanding and learning. In a recent study, Southerland, Abrams, Cummins, & Anzelmo (2001) suggested two distinct models of learning that may inform us to better understand student explanations. First, a mental-model-based perspective wherein "learner's conceptions are thought to exist inside the learner's head in conjunction with other related conceptions to form a large and complex conceptual framework for a topic" (p.329). The second model is the idea of "knowledge in pieces" introduced by diSessa (in Southerland et al., 2001). In this perspective, student explanations are often assumed as spontaneous constructions and not as reflection of coherent theories and systemic frameworks. diSessa refers to these knowledge pieces as phenomenological primitives (p-prims) that are "atomistic knowledge structures that are unconsciously activated by the learner in response to a particular situation" (Southerland et al., 2001, p.329).

Southerland, Abrams, Cummins & Anzelmo (2001) investigated the patterns and consistency of students' biological explanations in different grade levels. They had participants from second, fifth, eighth, and twelfth grades. They interviewed the students, and during the interviews they showed a series of pictures of natural phenomena, and asked a series of questions to explain the phenomena present in the pictures. In their study of students' biological

explanations, Southerland et al. (2001) used the following categorization: anthropomorphic, teleological, mechanistic proximate, mechanistic ultimate, predetermined, don't know, and blended. The first four items in this categorization have been already defined in the previous paragraphs. Predetermined explanations are explanations that use god, nature or an identifiable agent. For example, "The cactus has thorns 'cause it's made that way" (p.332). Blended explanations were defined as explanations that include more than one of the previously mentioned categories. "Don't know" category referred to no answer or literal "I don't know" answer.

Southerland et al. (2001) found that students have both tentative and shifted explanations for biological phenomena. When students are probed several times, they can give different types of explanations for the same phenomenon. For instance, first providing a teleological explanation, and then giving mechanistic proximal and predetermined explanations.

The tentative explanations are characterized with phrases or sentences that indicate undecided expressions or possibilities of explanations, for example, "I guess," or "I don't know, but maybe it's..." (Southerland et al. p.337). Tentative explanations are given before the final explanations.

Another finding of their study was that mechanistic ultimate explanations were seen mostly among the twelfth grade high school students, suggesting that there is a correlation between the increased age and the complexity of the explanation.

In their discussions, Southerland et al. (2001) suggested the possibility that since many shifts were observed in students' explanations, the p-prims model of diSessa was more likely to explain their results. As opposed to more coherent explanations, the shifting explanations support the idea of 'knowledge pieces' spread in the learners' mind ready to be stimulated for particular

situations. On the other hand, they also indicated that the shifting character of explanations may be due to the nature of their interviews. Southerland et al. (2001) thought that interview probes like “why do you say that” or “help me understand that” might have influenced students’ explanations so that students felt their answers are not acceptable. Possibly, the students might have changed their explanations in order to provide more acceptable explanations.

Southerland and her colleagues’ (2001) research had important implications for classroom teaching. If students’ explanations are reflections of already shaped existing frameworks, a conceptual change approach will be a more beneficial instructional strategy. In this strategy, students are presented with alternative theories and given tasks to analyze or evaluate those alternative theories. The expectation of this strategy is that students will replace their existing conceptions with more appropriate conceptions or formulations of ideas. On the other hand, if students’ explanations are reflections of small pieces of information that are not coherently organized (p-prims), then different instructional strategies will be appropriate. In this case, instruction should focus on developing patterns and regularities among those pieces of information. Instead of challenging students to choose among different theories and ideas, instruction should help students to build meaningful structures from the existing pieces of information (Southerland et al, 2001). It is also a possibility that p-prims and conceptual frameworks co-exist in students’ minds, but one of them is more the dominant knowledge structure in a certain domain or topic.

With a companion paper to Southerland et al.’s (2001) study, Abrams, Southerland & Cummins (2001) investigated students’ explanations of biological change in organisms. Abrams et al. found that students are unfamiliar and unprepared with the causal explanations in biology. For example, many students in their study could explain why birds migrate south (because of

temperature change), but couldn't explain how this biological reaction takes place. Abrams et al. (2001) argued that current biology curricula emphasize the "why" questions of the biology and do not address the "how" questions. They brought Lemke's (1990) triadic dialog idea to their discussions. Triadic dialogs are a very typical pattern of dialog in most classrooms. In triadic dialogs, a teacher asks a recall question, students respond to the question, and the teacher assesses student responses. As Abrams et al (2001) pointed out, triadic dialogs do not stimulate higher order thinking. Therefore, in classrooms where triadic dialog is the dominant type of discourse, students have difficulty to answer questions that require an explanation of a process or mechanism.

Studies show that there is a relation between the ages of students and the quality and level of their explanations. Metz (1991) investigated the development of scientific explanation among 32 children aged from three to nine. She asked the children what would happen when you turn a knob in a series of gear configurations. Metz found that incremental and fundamental changes occur in children's explanations by increased age. She categorized three distinct phases of explanations, which represent the developmental stages in children's explanations. Children in the first phase provided explanations that have attributions to the function of the object. The following quote, for example, refers to the function of a knob: "Cause the handle is there" (p.789). This type of explanation does not attribute any causality to the system.

In the second phase, the level of the explanation was increased for children to make connections among the gear elements. An example of this type is given as follows: "Cause that one's attached to that one, and that one's attached to that one, and that one..." (p.789). In the final phase, children provided mechanistic/causal explanations, for example, "Because if you turned that one it'd be turning that one, and that one'd be turning that one, and ..." (p.789).

Metz (1991) considered the change from phase two to phase three as a fundamental change, because a mechanical explanation is “a fundamentally more adequate account of the phenomena” (p.796). Metz’s research suggests two types of fundamental change, radical substitution and transforming incorporation. In radical substitution, a new explanation replaces the former one. In transforming incorporation, the former explanation is not completely replaced, but it is transformed to a higher level so that a fundamental change happens in students’ understanding of the causality.

Mayer’s (1992) categorization of three different views of explanations was presented in our review of philosophy of science. Although those three views came out of a philosophical review, Driver et al.’s (1996) empirical study with students gave a very similar result to those views. Driver and her colleagues studied many aspects of students’ understanding of the nature of science among nine, 12, and 16-year-old students. At the end of their extensive work, they provided a framework for characterizing students’ epistemological reasoning. Their framework suggested three distinct forms of reasoning: phenomenon-based reasoning, relation-based reasoning, and model-based reasoning. According to Driver et al. (1996), each of these reasoning forms has distinct features regarding the nature of explanation and relationship between explanation and description. In their framework, the simplest form of reasoning is phenomenon-based reasoning. In this form, explanations are simply descriptions and there is no distinction between an explanation and a description. The intermediate form of reasoning in their framework is relation-based reasoning. In this form of reasoning, explanations are empirical generalizations, which are derived from the observations on the phenomenon. Explanations emerge from the data, different variables, and linear causal links can be recognized. There is an inductive relationship between explanations and description. Students recognize that description and

explanation are different but they all refer to observable and existing conditions. In a relation-based form of reasoning, students also think that theories can be proven, based on evidence. The final form of reasoning in Driver et al.'s framework is model-based reasoning. In this form, explanations are based on models and theories. More than one model or theory can be involved in an explanatory account, and theories and models are conjectural. The relationship between explanation and description is a hypothetico-deductive. There is a clear distinction between explanation and descriptions and it is recognized that an explanation cannot be deduced from observational data.

Driver et al. (1996) underlined that a student can shift from one form of reasoning to the other depending on the topic. Even in some occasions the primitive form, the phenomenon-based reasoning, can be the only option demanded from students. The results of their study indicated that phenomenon-based reasoning is more common among the youngest students. The relation-based and model-based forms of reasoning were more common among the 12 and 16 age groups. Driver et al. (1996) indicated that because of its complexity model-based reasoning is the least used reasoning among the students. Therefore, they suggest that in order to understand scientific problems where modeling is required, students should be explicitly taught about this type of reasoning.

Linn & Songer (1993) investigated eighth-grade student's views of science during a specific one-semester computer-assisted physical science course. Part of their focus was to identify the changes in students' views of scientific explanations that are initially identified as static (fixed) or dynamic (subject to change). Their results on this focus indicated that the character of students' explanations did not change significantly from pre-test to post-test. However, they identified that students lacked criteria for comparing different explanations.

Studies conducted among young children report that children usually present immature types of explanations with frequent incidents of tautology (redundant repetition of words or ideas), reaffirmation, teleology and juxtaposition (Solomon, 1986). These immature types of explanations can be characterized as pre-causal explanations. Solomon refers to Piaget's (1928, as cited in Solomon, 1986) idea that young children can rarely answer the "why?" questions with an empirical "because." Students, however, juxtapose the ideas already presented in the question. The following two examples represent pre-causal thinking of students:

Q. Gold can be found as a pure metal in the earth's crust. Iron cannot be found as a pure metal. Why is this?

A. Because iron is not found in the earth's crust. (Second year pupil)

Q. Use the idea of gravity to explain why neither the moon nor the small planet Mercury have any atmosphere, but the massive planets do.

A.. ...because it does not need an atmosphere because it is too small. (Third year pupil).
(Solomon, 1986, p. 43).

As the above examples suggest young children have very limited ability to give causal explanations.

Research in Cognitive Science

Many educational psychologists (Krupa, Selman, and Jaquette, 1985; Metz, 1991) hold the view that children undergo developmental stages so that their ability to grasp the scientific concept and ideas and therefore their ability to explain increases as they get older. Given the relationship between one's level of development and the level of explanation he or she can provide, Krupa et al. (1985) defined the explanation as follows:

If a one-to-one correspondence is identified between subjects' level of science explanations and their level of operational development, we might conclude that science explanations are simply a particular manifestation of logical structures; that the particular content of phenomena examined does not "resist or yield" in any different way than does the content of the tasks used to reveal Piagetian operational thought (p. 432).

Krupa et al.'s (1985) study among children from different age groups ranging from age three to 18 suggested four different developmental levels of scientific explanations. The study was in a context of two physical science topics, gravity and electromagnetism. At very early ages, children can perceive only overt aspects of the phenomena that are subject to be explained. In the next level, children can realize the existence of unseen events. However, it will take another level for children to make coordination between multiple unseen forces. Children at seven to 15 years of age can make coordinated explanations of unseen forces. In the final level, students can make balanced system explanations that are the balancing of relationships among multiple unseen forces. The age range of the final stage is 12 to 18. Krupa et al. (1985) suggested that these four developmental levels of explanation parallels Piaget's theory of logical reasoning. For instance, children at Piaget's *pre-operational thinking* level can make explanations that are defined in the first level of Krupa et al.'s (1985) study. Balanced system explanation, which represents the highest level in Krupa's study, can be made children who are at the *formal operational thought* level, the highest level in Piaget's classification.

There are studies that tested the effects of self-explanations on students' problem solving abilities and their understanding and learning of the subject (Chi, Bassok, Lewis, Reimann, Glaser, 1989; Chi, Leeuw, Chiu, & Lavancher, 1994). Chi et al.'s (1989) study analyzed the good and poor students' self-explanations that are elicited in the form of talk-aloud protocols

during a physical science unit. Their research indicated that students who are defined as good generated much more self-explanations than those defined as poor during their laboratory work. The self-explanations generated helped students refine and expand conditions of actions involved in the experiment, such as reasoning why a particular method is advantageous during the experiment. Chi et al. (1989) asserted that providing self-explanations improve the ability to solve problems.

In a similar study, Chi et al. (1994) studied the effect of self-learning on understanding. In the study, students who made self-explanations of read text were more successful in gaining knowledge than students in the control group who were not prompted to give self-explanations.

One distinct feature of explanations is that they often represent generative relations. Ohlsson (2002) proposed “an explanation explains by describing how the explanandum came to be” (p.95). In other words, according to Ohlsson, an explanation is a descriptive account of a series of generative relationships. Ohlsson provided a table of English phrases that express a generative relationships. The items in this table were as follows: “X allowed Y, X brought about Y, X caused Y, X created Y, X enabled Y, X engendered Y, X forced Y, X gave birth to Y, X gave rise to Y, X generated Y, X lead to Y, X originated Y, X produced Y, and X was a sufficient condition for Y” (p.100). These phrases can be useful in stimulating student thinking, especially when students are encouraged to think in terms of generative relations. Students, at least, can identify the relationships between different variables, if not the nature of relationships.

Ohlsson (2002) pointed out that a list of events that precedes Y is not a sufficient explanation. In order to have a satisfactory explanation, one should “specify the manner in which the preceding events were instrumental in bringing about Y” (p.101). According to Ohlsson, this degree of specification draws the line between an explanation and description.

Ohlsson (2002) also indicated that most of the explanations in science are in the form of explanatory schemata which involves multiple generative relationships. Ohlsson defines the schemata as “a template or a recipe for how to construct an explanation of a particular type” (p.110). In his conclusion, Ohlsson provided a cognitive model of an explanation generation process. In this model there are several different factors involved. First of all, a number of generative relations are retrieved from the person’s prior knowledge and experiences. While simple daily life explanations do not require a schema assembly, most of the scientific explanations require a schema assembly. This explanatory schema, then, needs to be articulated. According to Ohlsson, the simplest form of articulation involves replacement of constants with variables. In more complex forms, articulation of explanatory schema involves some creativity, subsets of schemas, domain-specific facts, and so forth (Ohlsson, 2002).

Conflict resolution is the next step in the cognitive process of providing an explanation. There may be more than one alternative to explain one phenomenon and a decision to choose one explanation might be required in order to resolve the conflict. This step involves probabilistic decisions. The final step of the process is the verbalization in which explanation is represented in a discourse form and communicated with other people (Ohlsson, 2002).

Wong (1996) studied both students’ and scientists’ scientific explanations in their contextual settings. In his analytical essay, Wong argued that students’ explanations are affected by several factors: (a) knowledge and technology available; (b) the sociolinguistic norms inherent in a context that implicitly define what ‘counts’ as reasoning; and (c) the expectations, values, and dynamics of school communities (p. 497). These factors have important implications for classroom teaching. Wong (1996) points out that students’ misconceptions should not be dismissed without considering the nature of thinking and reasoning involved. Wong continues:

“realizing incorrect explanations are often based on sound reasoning and real observations or experiences helps explain the intransigence of misconceptions to change”(p.507).

Research indicates that humans have tendency to explain the phenomena with the closest agent of change or effect (Murayama, 1994). This is even true for adults. For example, Murayama asked undergraduate and graduate students in an interview for an explanation to the question why a vacuum cleaner sticks to a carpet. A typical non-mechanical (non- causal) answer to this question was “the vacuum cleaner pulls the carpet” (p. 198). A mechanical answer to this question, however, would require the articulation of an understanding of air pressure physics. The above reasoning is pre-causal, since the answer is given in terms of agents, but not real causes. In his article Murayama argues that causal reasoning is triggered by “anomaly detection through comparison with natural events” (p.205). An anomaly refers to an unordinary situation or a deviation from normal and humans are more likely to perceive an unordinary event than an ordinary one. Murayama (1994) provided the example of falling or standing objects. When objects fall or stand, there is no need for explanation because their behavior is all natural. However, starting to fall is a deviation, because an object lost its support and there is an anomaly situation.

Personal views (Hogan & Maglienti, 2001) and biases are also important in scientific reasoning and providing explanations. Ego-protective reasoning can easily arise to provide an explanation as opposed to explanations provided by cognitive reasoning (Klaczynski & Narasimham, 1998). According to Klaczynski & Narasimham, ego-protective reasoning can play an important role in psychological health. The research in this field indicates that when people are presented with new evidence, if it is consistent with their preexisting knowledge, beliefs or personal goals, they are more likely to accept new evidence. Klaczynski & Narasimham (1998)

indicated “these biases promote individuals’ self-esteem and allow them to bestow on themselves the positive qualities of groups to which they belong and to protect themselves against attacks to their self- or group-related beliefs” (p.185). This research could have important implications for the students’ explanations of publicly controversial science topics, such as evolution and biotechnology.

Summary for research in students’ scientific explanations. Researchers in the field studied different aspects of explanations, and used a wide variety of techniques to study explanations. Although researchers used different techniques such as interviews, multiple choice items, survey questions, and drawing to study students’ scientific explanations, there has not been much research that uses writing. Linguists (Halliday & Martin, 1993, Unsworth, 2001) accept explanations as scientific genre, and provide us with general characteristics of explanations. This information suggests that increased and systematic use of explanation genre by students can improve the quality of their explanations.

Writing is perhaps the most advantageous strategy to enhance students’ explanations. Writing requires one to organize his/her ideas, and to have complete and warranted understanding to communicate with the public (Keys, 1999). Writing not only stimulates student thinking and reasoning but also helps students to become accustomed to genre characteristics of explanations. Therefore, two suggestions can be made. First, research in this field should give more emphasis to writing tasks in order to study scientific explanations. Use of writing in the research of students’ explanations can greatly contribute to our understanding of the cognitive aspect of explanations due to the very close relationship between writing and thinking. Second, teachers should use writing tasks more often to develop student reasoning related to the scientific explanations. In particular, science laboratory work should be supported with writing tasks that

specifically address explanations. In science laboratories, students have opportunities to make observations, and collect and analyze data. Students also have a certain theoretical knowledge base of their own and knowledge base they just gained from the relevant laboratory topic. Therefore, students can potentially develop one of the three types of explanation reasoning defined by Driver et al. (1996). As opposed to decontextualized survey or test items, writing tasks situated into inquiry-based science laboratories provide more opportunities for researchers to better examine explanations and help students construct authentic explanations.

CHAPTER 3

METHODS

Overview of the Research Design

This was a qualitative and interpretative research study that used methods of interview, content analysis and observation. I used genre (Halliday & Martin, 1993; Veel, 1997) and functional linguistic (Eggins, 1994; Halliday, 1985) approaches to analyze the content of students' writing. The purpose of the research was to understand the nature of high school students' scientific explanations and describe the ways students construct scientific explanations. More specifically, the following were the research questions that guided the research:

- 1) What are students' meanings of scientific explanations?
- 2) What are the characteristics of high school students' scientific explanations?
- 3) What is the nature of students' epistemologies related to the scientific explanations?
(e.g. source knowledge or evidence drawn upon to provide an explanation).
- 4) To what degree do students' explanations represent the characteristics of
explanation genre identified in the literature?

The interpretivist research tradition in social sciences emerged as a reaction to positivist and post-positivist approaches to the social sciences. Unlike a positivist methodology which aims to determine the causal connections between various natural phenomena, or between social phenomena in social sciences for that matter, interpretivist research aims to understand the meaning of phenomena (Crotty, 1998; Schwandt, 1994). As Schwandt (1994) noted, in interpretivist research "the inquirer must elucidate the process of meaning construction and

clarify what and how meanings are embodied in the language and actions of social actors” (p.118). Interpretive research provides descriptions, general explanations, and it emphasizes the uniqueness of the setting. The focus of interpretive research is often human experience.

Although there are different sub-variants of interpretivist perspective (e.g. phenomenology, symbolic interactionism, hermeneutics), I did not subscribe to a specific form of interpretivism. I used interpretivism as a general approach to attend the meanings students created in their explanations and to interpret those meanings. Nonetheless, some premises of symbolic interactionism fit the purpose of my research. At the center of the symbolic interactionism are meanings. In a symbolic interactionist perspective, “humans act toward the objects and entities on the basis of the meanings that these things have for them” (Schwandt, 1994, p.124). By communication these meanings are shared between members of a community and these meanings are established or modified through interpretive processes (Schwandt, 1994). As I pursued my research to find out the meaning of explanations for students, I accepted what students understood from the explanations questions that I posed were related to the meaning students had for explanations. How students perceived the act of explaining, consciously or unconsciously, affected their approach to how to answer explanation questions. In my study I tried to characterize students’ scientific explanations in terms of patterns observed, their epistemologies, and some linguistic characteristics. I did this by interpreting their writings using the content analysis techniques (Eggins, 1994, Halliday 1985).

Subjectivity is an important concern in interpretivist research. The lenses that a researcher looks through his/her research context, actions of participants, and the artifacts of the research can influence the interpretation that researcher provides. Therefore, in this section I shall talk about my personal epistemology to reveal some of my subjectivity. My epistemological

stance is parallel to social constructivist ideas. I believe that social interaction and socially accepted forms of thinking are as influential as individual differences in the learning process and outcomes. Learning process involves the learner's active engagement and participation rather than they being passive receivers of knowledge. Understanding involves meaning making, which is made through the language. Knowledge can hardly be transmitted from a teacher to a learner without any transformation in the head of the learner. During a transformation process learners create their own meanings of the knowledge by means of language. Language limits the possible meanings one can make from a learning action or interaction. Since different meanings are attained by learners and shared among others, for effective communication negotiation of meanings is important. Shared values within the community of learners, and the values of the society where the learners belong influence the learning process. For instance, an argument like "if humans evolved from apes, why do we have chimpanzees today", appears to represent a way of thinking affected by social values. I do not think students in this study or elsewhere who use similar arguments like concur as a result of their individual assessment of evolution theory, but they simply echo anti-evolution arguments imposed by their societies or communities.

I realize that students bring different conceptions of scientific ideas than those in the curriculum. Interaction between learners, sharing and negotiation of ideas brings new meanings. I believe that learning in science labs involves processes of both a cognitive apprenticeship (Roth, 1993) and a discursive apprenticeship (Veel, 1997). Group work in science laboratories enables students to learn from each other; and students who have less understanding of the topic can enhance their level of learning they can achieve individually by means of interacting with more expert students. Therefore I accept Vygotskian (1978) notion of *the zone of proximal development*. I also believe that students' practice of science is a form of discursive

apprenticeship where students get acquainted with the scientific languages and its genre types (e.g. report, observations, explanation etc.) and adopt the type of discourses favored by scientific communities.

School Context

The high school where the data was collected is located in a rural area in northeast Georgia. At the time of the study, the school had about 1350 students. About 88 % of the students were White, nine percent were African-American and two percent were Hispanic. Thirty- two percent of the students in the school were eligible for either free or reduced price meals. In the 2002-2003 academic year, the average SAT score was 929 for the school, while the state average was 980 and the national average was 1016. The graduation rate for students was 49%, which was below the Georgia state level, 63%.

Participants

Participants of this study were 16 tenth grade high school biology students in two different college preparation classes taught by the same teacher. Ten of 16 students were female and the remaining six were male students. Seven of the students were in the first period class, and nine students were in the second period class. Of the 16 students, 13 were in the full participant category allowing the researcher to make copies of their laboratory reports, interview them individually and audio tape the group discussions during the laboratory activities. The other three students permitted the researcher to access only written data. Students in this study can be described as average level success students based on their class placement. All participants were Caucasian. Though participants were selected by volunteering, classes from which the data was collected were chosen for their average success level. From a researcher's perspective, the reason

for working with average success level students was to eliminate possible extra time and effort required while working with lower and higher achieving students.

Prior to the start of school semester, I talked to several biology teachers in the school. I decided to work with a single teacher who had a flexible schedule and was more than willing to work with the researcher. Although I initially planned to work in one class period, I conducted my research in two consecutive class periods in order to maintain the desired participant number.

After the teacher and the classroom periods were determined, I explained the purpose of the research to the students and invited the students to become participants. I explained the procedures and what would be expected from students as a result of their participation. I read the consent and minor assent forms aloud in the classroom, and answered students' questions in that regard. All students were given consent and minor assent forms. All of the students who volunteered were included in the study. Table 3.1 shows pseudonyms of the students, their class periods, and participation level.

Table 3.1

Participant students

Student	Class Period	Gender	Level of Participation
Bart	First	Male	Full
Allison	First	Female	Full
Kimberly	First	Female	Full
John	First	Male	Full
Tracey	First	Male	Full
Janice	First	Female	Partial
Anthony	First	Male	Partial
Ben	Second	Male	Full
Noah	Second	Male	Full
Laura	Second	Female	Full
Macy	Second	Female	Full
Sandy	Second	Female	Full
Nikki	Second	Female	Full
Amy	Second	Female	Full
Barbara	Second	Female	Full
Elizabeth	Second	Female	Partial

Classroom context

The classroom teacher had 17 years of teaching experience by the time data was collected. As understood from informal interviews with the teacher, she acknowledged the value of inquiry-based teaching and learning. However, being constrained by external factors, such as limited time, amount of curriculum content to cover, standardized exams etc., her practice of science teaching was not a good example of inquiry-based instruction.

The teacher often used overheads to give brief lectures, had the students fill out worksheets, or gave quizzes to the students. She often had the students draw figures and illustrations that represented biological entities (e.g. organisms, organelles, organs, and structures). She asked questions that required short answers and used “fill in blanks” type of exercises.

The types of classroom activities that the data was collected through were not typically those followed by the regular teacher. For instance, the writing involved in the laboratory reports, and science letter activities were not tasks that students were accustomed to. Thus, the majority of students needed time in adjusting to the task required in the SWH reports, such as making a claim and providing evidence.

Prior to the actual data collection, in the first laboratory of the semester, an initial activity, Gummy Bear, was given to students. In this activity, students were introduced to the format of SWH. Students were encouraged to ask questions about the parts or sections they did not understand. At the end of this laboratory, a whole class discussion on claim, evidence and explanation was facilitated by the researcher and the teacher.

Description of Activities

The data was collected during six science laboratory investigations in the Spring 2003 semester. The first of these investigations, gummy bear laboratory, was intended to warm up students to the intervention used. Table 3.2 represents the science laboratory investigations from which the data were collected.

Table 3.2

Science laboratory investigations

Name of the Investigation	Date	Purpose of the laboratory investigation	Explanation Problems (Briefly)
Gummy Bear (Pilot activity)	1-8-2003	Students will use scientific method and measurement to predict what will happen to a gummy bear after it is soaked in water overnight.	Explanation of change in gummy bear candy.
The Effects of Acid Rain	1-24-2003	Students will measure the pH of a water solution to observe seed condition and germination. Interpret data showing differences in seed germination under varying pH conditions.	Explanation of how acid rain interferes with the seed germination.
Diffusion and Osmosis	2-3-2003	Students will a) observe osmosis across the membrane of an egg and b) measure the amount of water that moves across the egg membrane.	Explanation of water movement in and out an egg under different conditions.
Sickle Cell Anemia	3-10-2003	Students will identify the genotypes of the members of a family using the DNA gel electrophoresis technique.	a) Explanation of the cause of sickle cell anemia disease. b) Explanation of why (S) alleles are maintained in places where malaria disease is common.
Evolution	3-27-2003	Students will investigate whether apes share a common ancestor with human beings.	a) Explanation of whether human and apes have a common ancestor or humans evolved from the apes. b) Explanation of whether humans and chimpanzees have a common ancestor.
Fungi	4-17-2003	Students will observe the growth of fungi on different food sources and explain how different conditions stimulate or inhibit fungi growth.	Explanations of different amount of fungi growth under different conditions.

Leaf Stomata	5-15-03	Students will determine the location and density of stomata on a leaf, and describe the effect of an environmental change on stomata.	a) Explanation of the different number of stomata found on the different surface area of a leaf. b) Explanation of how guard cells respond to hot and dry conditions.
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The topics and the order of the laboratory activities were temporarily determined at the beginning of the semester. As the semester progressed, the researcher and the teacher decided the exact dates of the laboratory activities. Typically, after each laboratory investigation ended, the next laboratory investigation was briefly discussed by the teacher and the researcher in the classroom. The researcher then prepared laboratory sheets for the next activity approximately a week before the planned activity day and e-mailed them to the teacher to make copies.

The science laboratory investigations that students conducted can be considered as “structured” inquiry labs (Schwab, 1962) because students did not come up with their own research questions, did not select the variables, nor did they have a choice to modify the investigation conditions. Students were also provided with data tables, even though they were given the option to create their own. On the other hand, students had to interpret their data and evidence, and make claims and explanations. The claim and explanation questions in the laboratory sheets also guided student thinking. For instance, when students were asked the question “what claims can you make about the effects of the NaCl solution on leaf guard cells and stomata?” their attention was directed to a specific aspect of the investigation. Similarly, explanation questions specified the phenomenon to be explained, instead of students choosing which phenomenon required an explanation. Nonetheless, students made their claims and explanations based on their individual experience as well as experience they had in the group

work. Students were encouraged to discuss their data and evidence with their peers. However, they were instructed to write their own explanations.

Data Sources and Collection

Two distinct sources of data were collected in this study: written data and audio data. Written data consisted of students' laboratory reports and science letters. Audio data included individual interview data and recording of group discussions. The interview data primarily helped to answer research question one: "What is the meaning of explanations for students?" Semi-structured interview questions were created to answer this question. Interview data also helped to answer research question three, "What is the nature of students' epistemologies related to scientific explanations?" Students were asked what type of knowledge source (e.g. first hand experience, textbook, teacher) they used in order to make explanations. However, written data also helped to answer this question. Analysis of written data revealed how students used empirical evidence or theoretical evidence in their explanations.

The written data helped answering research question two, which was related to the patterns and characteristic of students' explanations in terms of the thinking (e.g. using evidence, making inferences, identifying causes) involved in them. Written data also helped to answer research question four, which was about the genre structures involved in students' explanations.

The audio data from the students' group discussions is excluded from the analysis, because noise from other groups interfered with the conversations within groups and there were frequent off-topic talks, which made transcription and analysis very difficult.

Procedures Related to the Intervention

The current study utilized an intervention called Science Writing Heuristic (SWH), (Keys et al. 1999). More detailed information about SWH and a summary of the research that used

SWH is provided in the previous chapter. The SWH student template (See Table 3.3) was embedded into students' laboratory sheets. In the context of the current study, emphasis was given to student template of the SWH, which was modified slightly from its original version. While the reading and reflection steps are eliminated, an explanation part is added to the list of student tasks. Because of teacher time constraints, the last two steps of the SWH student template were eliminated. However, students were guided toward thinking about the meaning of observations, claims, evidence and explanation, especially in the first few laboratory investigations. The first step of the SWH, beginning ideas, was covered in the pre-laboratory discussions; observations, claims, evidence, and explanations were included in the analysis and conclusion part of the student laboratory sheets, which will be described shortly.

Table 3.3

Science Writing Heuristic student template

- 1-Beginning ideas—What are my questions?
- 2-Tests-What did I do?
- 3-Observations –What did I see?
- 4-Claims—What can I claim?
- 5-Evidence—How do I know? Why I am making these claims?
- 6-Reading-How do my ideas compare with other ideas?
- 7-Reflection-How have my ideas changed?

For each lesson that was part of the data collection, the classroom teacher wrote the agenda for the day on the board. Either the researcher or the teacher, sometimes both, facilitated the pre-laboratory discussions. In some labs, as the researcher was busy with setting up the laboratory equipment at the beginning, the teacher started and led the pre-laboratory discussion. Otherwise, the researcher facilitated the pre-laboratory discussion sessions. In most cases, the researcher explained the procedures and the use of equipment to the students. The teacher also

made her own precautions regarding safety issues and gave directions to students to follow the instructions when she felt necessary.

The laboratory sheets used in data collection typically included the following sections: purpose, problem, research, getting ready for the hypothesis, hypothesis, experiments/procedures, data/observations, and analysis and conclusions (see Appendix D). The purpose and the problem sections briefly informed the students about the overall purpose of the activity and research problem undertaken. The research section of laboratory sheets provided the background information about the problem investigated. The basic information relevant to the problem was included in this part. After being given the background information and the stated problem, students were presented with a simple warm-up thinking activity to get them ready to make a hypothesis.

In getting ready for the hypothesis, students wrote their responses to the given question in few sentences and shared them with the class. In the next step, students developed their own hypotheses regarding the problem and wrote their answers to their laboratory sheets. In the experiment and procedures section, step-by-step instructions to conduct the investigation or the activity were provided. Most of the time, the researcher, as he introduced the equipment and the material, verbally explained the procedures to the students. In the data/observations part, students typically filled out a chart to record their quantifiable data and qualitative observations. A chart template was provided for students where relevant. However, students were also given the option for designing their own chart.

The analysis and conclusion part included four sections: observations, claims, evidence, and explanations. Students, first, wrote down their observations as answers to content specific questions. Students then made scientific claims from their data and observations. In the next

section, students were asked to provide evidence for their claims. In most of the cases, students were asked to provide more than one claim and more evidence was to be provided too. In the last part of the laboratory sheets, students were asked to explain a phenomenon or problem relevant to their laboratory activity. In the acid rain and sickle cell anemia labs, students were asked to read an extra page of information before they made their explanations (See Appendix D).

While preparing the laboratory sheets, the researcher relied on the language of school curriculum and the graduation tests that student would take. For instance, in defining the scientific method, students were exposed words such as “problem” and “research”, and those were the words they would encounter in graduation tests. Although the researcher preferred to use the word “question” instead of the word “problem” and “background information” instead of “research” in some cases, he chose the words that students were supposed to know in their tests.

In a typical laboratory, first, laboratory sheets were passed to students and the purpose of the laboratory activity explained to the students. Students then read the background information about the problem or topic. After this, five to ten minutes were spent for questioning and brain storming activities. A whole class discussion was facilitated by the researcher and the teacher. Students were encouraged to share their ideas with their classmates at this stage. Students wrote down their responses to the “getting ready for the hypothesis section.” Following this, students wrote their individual hypotheses. In the next step, students were given the procedural instructions for the laboratory activity, precautions for laboratory safety, and efficient use of tools and materials.

In both classes where the data were collected, students usually worked in groups of four. Students who were full participants grouped together so that their discussions in the groups could be audiotaped.

When students finished writing their laboratory sheets, they brought their papers to the teacher's desk. The researcher took all of the papers to grade. The researcher, however, copied only work of the students who gave permission for copying. All the laboratory activities were part of the classroom instruction; therefore there was no difference between the participant students and non-participants students in terms of the tasks involved.

Procedures for Science Letters

At the end of the gummy bear, acid rain, osmosis, genetics and stomata investigations, students were given the task of writing a science letter. These letters intended to improve students' ability to make explanations. From a research perspective, it provided an alternate venue to look at students' explanations. In the science letter writing activities, students had opportunities to apply the concepts, ideas, or theories into different situations. In each letter, students were provided with a different case or scenario involving a scientific phenomenon that was the subject for an explanation, for example, a genetic problem faced by a pregnant woman. Here students were asked to write a letter and explain the scientific phenomenon to a person who supposedly had no knowledge of the phenomenon. For another example, students wrote letters to a summer camp director who was in a position of authority to decide students' eligibility for the summer camp. Students were provided with a rubric and grading criteria. Students wrote their letters in class time, while some students opted to write their letters at home or they did not have time to finish their assignment during the class period so they wrote at home. These students handed their assignments in the next day.

Procedures for Interviews

I interviewed the students toward the end of the semester, starting after the evolution laboratory investigation. The thirteen full participant students in the study were individually

interviewed. Interviews lasted 25-40 minutes each, and I transcribed all interviews. Interviews took place in an empty classroom or school cafeteria depending on the availability, with empty classrooms being preferred for minimum interference. Interviews were conducted during the class periods; the teacher helped to choose whom to interview considering the students' ongoing tasks.

Interviews were structured with some pre-determined questions (see Appendix A), and more questions were asked depending on the flow of the interviews. At the beginning of the interviews students were reminded that their responses would not affect their classroom grade. During the interviews students were asked to create a concept map for the scientific explanations. Each student was provided with a paper sheet on which "scientific explanations" was written in an elliptic balloon (See Appendix B). Students, then, were given the instructions to create a concept map that includes relevant features of scientific explanations, such as the characteristic of good explanations or components of a scientific explanation. After the completion of their concept maps students were asked to provide a brief comment for each item in their concept maps.

During the interviews students were asked to elaborate on the written explanations they provide for science laboratory reports or in some cases they were asked to give an explanation for the questions they left blank in the laboratory sheet. The reason for doing this was to get a verbal account of students' explanations, and create an opportunity for the students to say things they could not be able to write on their laboratory sheets. This also helped with triangulation of data. My focus was mainly on the sickle cell anemia, osmosis, and fungi laboratories. The sickle cell anemia laboratory required a causal explanation and the osmosis laboratory required a theoretical explanation. Therefore, during the interviews, these labs were worth extra attention

for the unique type of explanations they offered. The fungi laboratory was also chosen to follow up during the interviews because students' experiment results varied considerably. Since the students' data yielded different results I was interested in probing their ideas about the fungi laboratory data. For this reason, students were asked to explain the inconsistency between the textbook knowledge and their results. I intentionally did not ask questions from the evolution laboratory, due to the tension that emerged during the laboratory activity. Some students expressed their discomfort in studying this topic. By the time the interviews were being conducted, the stomata unit had not been covered, so the stomata unit, along with the introductory laboratory (gummy bear) were excluded from the interview questions.

Teacher and Researcher Roles During the Laboratories

In the beginning of the semester, both the researcher and the students were apprehensive working together. As a researcher it was a unique experience for me to be in an American classroom. For many students in the class, working with an international researcher was not something of the ordinary. However, rapport was quickly established between me and students once we started working together.

I prepared all of the laboratory sheets that were used to collect data. I negotiated the type, subject, and duration of the laboratory investigation units with the classroom teacher. To some degree, the pressure on classroom teacher to cover the content was restrictive for me, for instance I felt that more classroom time could have been spent for some of the laboratory tasks.

I was present in the both classrooms for the entire periods when classroom laboratory investigations were undertaken, including post-laboratory activities, such as writing and discussions. I helped the teacher grade the material that was part of the data collection. When students asked for help both the teacher and I responded based on availability. The teacher and I

took responsibilities interchangeably during the instruction of laboratories. For instance, sometimes I introduced the topic to the students, led the pre-activity discussions that included questioning and hypothesis making, and gave the instructions as to the proper use of the equipment. However, the teacher had more power to manage the classroom than the researcher. She kept the time, decided when to move on, and disciplined the students who were not on task.

Although I observed and helped all the students groups in the classrooms, I spent more time with the participant students' groups. I answered the students' questions about the procedures, gave confirmation to students whether they were on the right track because the researcher wanted to make sure that students yielded data intended for the purpose of the research. Sometimes I asked questions to the students during the laboratory activities in order to facilitate the discussions and foster brainstorming. However, I refrained from giving explicit answers to student questions that may directly affect their written responses. The following conversation that took place during the osmosis unit between students and me represents the role that I took.

Bart: ...cause I was about to say, how can you know how much the egg is shrunk or grew up if you don't know how big it was in the first place, cause those are bigger than those

Researcher: uh

Bart: But you can't really measure an egg

Researcher: ...but with this [indicating a graduate cylinder] you can get an idea if your egg absorbed vinegar or it...

Bart: ...and what about evaporation though

Researcher: Well, it's a good question, what do you think?

John: I don't know, depends on what you got covering it

Researcher: For one day... do you think now, what do you think about the evaporation?

Bart: I don't know

Researcher: um, do you think there is going to be too much evaporation tonight?

John: Well, it depends on what you cover it with, you know, if you cover it with like plastic,

Bart: You're going to have water droplets

John: Yeah, you can't get, water can't get out of plastic I don't think, but you know paper towels, they'll just absorb it

Feedback for Students

During the laboratory activities, I closely observed the students and answered the students who were unclear or confused. I also graded the students' papers and provided written feedback on the students' responses. When the students had a misconceptual understanding, I tried to direct the students to think about the ways that they can give more conceptually sound answers. These comments did not affect the data since the data was already collected for the particular unit. I wrote comments for students who left some sections of the laboratory sheets blank, indicating the ways they could have thought in order to make an explanation.

Sources of Information Available to Students

The classroom teacher imparted the basic knowledge on the specific unit. During the labs, the most relevant background information is summarized in the laboratory sheets. For instance, students learned the concepts and terms such as gene, DNA, transcription, etc. in their regular class. However, the laboratory investigation in the genetics unit was a specific case for sickle cell anemia disease. Therefore, the basic information about the genetics of this disease was provided in the laboratory sheets. When students wrote their explanations they were encouraged

to use their first-hand knowledge (data, observations and evidence collected), the background information given in the laboratory sheets, and their prior knowledge. In two cases (the acid rain and the sickle cell anemia laboratories), students were asked to read extra material that was attached to their laboratory sheets. Students were also encouraged to look into their textbooks to help with their explanations; however they were discouraged from copying their answers from the textbook. From the observations the researcher made in the both class periods, students used their textbook considerably less than the expected. In many cases, the explanation tasks required students to make inferences from the data, so textbook knowledge in itself was not enough to provide a satisfactory explanation.

As explained in the researcher's role section, students had opportunities to ask questions of the researcher and teacher. However, the teacher and the researcher refrained from giving answers to explanation questions. Students were encouraged to discuss their data during the investigations. Before each laboratory started, a brief brainstorming activity took place, which was the "getting ready for the hypothesis" section in the laboratory sheets. During those times, students shared their ideas with the whole class. In some cases, students were given the option to take their science letter assignment home. In those cases, textbook information was available for students.

Missing Data

Despite all the efforts to sustain a continuous data set, there have been gaps in the data set. Some students were involved in extracurricular activities and missed classes. Some students were absent for unknown reasons. In a few cases, students were frustrated with the explanation questions and couldn't give an answer. There were also students who were overwhelmed with

the writing involved and did not write the explanation letter. Given the participant number, a total 96 laboratory reports were expected; however 70 laboratory reports were collected.

Data Analysis

Two sources of data were used in this research: students' writings and transcripts of individual student interviews. Student writings included students' laboratory reports and students' science letters, which accompanied science-writing activities that followed the regular laboratory.

In the analysis of students' laboratory reports two different approaches were used. One approach could be considered as content analysis based on genre characteristics of explanations. In this approach it was assumed that scientific explanation is a type of genre characterized with the logical/sequential organization of text and intensive use of action verbs (Martin, 1993). Furthermore, it was asserted by rhetoricians that explanations are "the only type of writing that has the development of understanding as its primary goal rather than informing, arguing a point or entertaining" (Chambliss et al., 2003, p.428). Given the unique characteristics of the explanation genre, and the strong relationship between thinking and writing summarized in the previous chapter, this strategy focused on the thinking and reasoning aspect of the students' explanations.

In the content analysis approach, students' written explanations were divided into smaller meaningful units. These units typically became a clause or clause with sub-clauses. In functional linguistics, a clause is accepted as the main organizational unit. A clause must have a subject or implied subject and predicative. A clause can include verbs to express actions and processes, nouns to identify participants and objects, and adverbs to express conditions such as time, place, and manner (Halliday & Martin, 1993). Each clause or analysis unit was believed to represent a

certain form of student thinking or reasoning. Therefore, codes were assigned for the function they serve in the text or the meaning or idea they convey in the text. These coded units could be, for instance, an observation, a cause, an effect, an inference, evidence, belief, etc.

Each set of laboratory reports was analyzed individually because each laboratory investigation had a different context, and so the nature of students' explanations was different for each unit. For instance, in the sickle cell anemia laboratory, the focus of the explanations was causal relationships, while in the leaf stomata laboratory the focus was predicting a physiological behavior. In order to understand students' scientific explanations with respect to a specific explanations task, each unit was analyzed separately.

All student explanations were typed in a word processor for each individual laboratory investigation, and each stand-alone idea represented by a clause or a sentence is separated by line breaks. Then, these clauses are coded on the word processor. At the outset, the researcher created a preliminary list of codes; however, during the process of analysis new codes were added and some of the codes that were in the preliminary list were eliminated, since there was not a significant occurrence of those codes. Some of the codes were also adopted from the schema that Schlesinger, Keren-Portnoy, and Parush (2001) developed to analyze arguments. After all the explanations were coded for a given unit, codes were refined. As noted, some codes were eliminated because they rarely appeared. Some codes were collapsed together when they achieved similar purposes (for instance, data, observation and evidence). After the codes were finalized and their numbers of occurrence were determined, they were tabulated for presentation. Similar strategies were used before by researchers to analyze students' science writings (Keys, 1999, Chambliss, Christenson, & Parker, 2003).

These strategies of analysis enabled me to identify the frequently occurring patterns in

students' explanations, for instance, how frequently students cite their data and observations, or factual information from book. These strategies also helped me to infer conclusions about the student thinking involved in students' explanations. For example, the number of cause-effect clauses in student explanations gave an idea about students' understanding of causality. Similarly, the number of inferences that students made in explanations tasks, helped me to understand whether students can make logical derivations. Overall, the distribution of codes in a given unit helped me to make assertions about students' epistemologies (e.g. sources of knowledge used) related to scientific explanations and patterns and characteristics of students' explanations.

The other approach of analysis was systemic functional linguistics. A systemic functional approach to linguistics is interested in two basic questions. First, how people use language, and second, how the language is structured for use (Eggins, 1994). In the context of this study, then, these questions can be reformulated as follows: How do students use language to construct an explanation? And, how is the language of students' explanations are structured? Questions of this sort can be answered with a focus on “authentic, everyday social interaction” (Eggins, 1994 p.2). Students' writings in this study were authentic in the sense that with few exceptions, all of the writings produced by students were as immediate responses to the science activities they did. Except for two instances where the researcher asked students to write their explanations after a short reading, the writings were produced in the class period with minimal interference from textbooks or any other external source of knowledge.

Considering the genre characteristics of explanations, functional linguistics offered two basic criteria to analyze students' explanations: lexical density and logico-semantic relations. Lexical density refers to the average number of content words per clause (Halliday, 1985).

Lexical density of a text can be determined as the proportion of the number of content words to number of all words in a text. Content words include, nouns, verbs, adjectives, and adverbs. Non-content words include, pronouns, prepositions, and conjunctions. The higher the lexical density, the more sophisticated the text. Specialized texts have more lexical density. For example, scientific texts have approximately 10 content words per clause. On the other hand, spoken language has two to three content words on average (Halliday & Martin, 1993). For instance in the following sentence, words presented in bold are content words, and they contribute to lexical density of the text.

“The **diffusion** is where **molecules tend to move** from an **area** where they are **more concentrated** to an **area** where they are **less concentrated**.”

The lexical density of students’ explanations were calculated for the answers to each explanation question for each unit and recorded in a spreadsheet. The average values of lexical density for each unit and student were calculated. Results were tabulated for the presentation.

Another criterion is logico-semantic relationships. Logico-semantic relationships refer to the links made between the clauses within a text using the conjunctions. When the links are made between different ideas represented by clauses, the writer expands the meaning of a sentence. The more links made between the clauses the more complex the text (Veel, 1997). Logico-semantic relationships can be represented in four main groups: additive (e.g. and, or), comparative (e.g. but, likewise), temporal (e.g. while, as, then, after), and consequential (e.g. so that, if, unless, because, since, although). During the analysis, for each unit, the types of the logico-semantic relations used by students are identified. This strategy also helped content analysis of student reasoning and thinking. For instance, when a student referred to a cause-effect

relationships, or a consequential relationship, it was evident in their use of conjunctions, such as “because” or “then”.

The data analysis that involved the lexical density and logico-semantic relationships helped me to answer research question four. Lexical density values represented the complexity of the language used. Thus, when the lexical density was higher, the students used a more abstract and complex language. Use of an abstract language suggests that students use the terminology of a theory, rather than here-and-now language. Identification of logico-semantic relationships also helped to understand the complexity of language. Particularly, higher use of consequential relations over temporal relations indicates the complexity of the language used; in consequential relations, students make connections among related events that represent a purpose, condition, manner or concession. Therefore, overall comparison of the use of consequential relations across different science laboratory investigations gave an idea about the linguistic qualities of students’ explanations.

In the analysis of interviews, traditional analytic approaches were taken to reduce data into smaller, more condensed pieces of information that helped to answer the research questions (Coffey & Atkinson, 1996). All interviews were fully transcribed by the researcher, and typed on a word processor. In the analysis of interviews, the researcher first focused on those sections of interviews that addressed a specific research question. Subsequently, the researcher concentrated on secondary or subordinate themes that emerged. During the analysis, marginal remarks (Miles & Huberman, 1994) were also made to highlight the significant points.

Definition of Main Terms

Empirical: Based on observation and/or experimentation.

Explanation: 1) To refer to the explanation section of the laboratory sheets, anything students

wrote for the explanation questions was considered explanation. 2) A statement or an account that provides reasons for why something happens or gives details about how something happens.

Exploration: A type of explanatory genre, it is used to account for events for which there is more than one viable explanation (Veel, 1997).

Laboratory: A classroom period or periods dedicated to a scientific experiment, investigation, or demonstration, which involves students' participation in hands-on tasks under the guidance of a teacher.

Lexical density: Number of content carrying words (e.g. nouns, adjectives, adverbs) per clause.

Investigation: Investigation refers to any laboratory activity that was guided and planned by the teacher (or the researcher). Regardless of the type of activity (experiment or demonstration), what students conducted during the laboratory period is called investigation.

Theoretical: Based on a specific theory, or a body of theoretical knowledge.

Codes and their definitions

Cause: Something that makes another thing happen.

Claim: To say something is happened or something is the outcome at the end of an investigation.

Conclusion: A final statement that emphasizes student's decision. In the context of this study, conclusion sometimes referred back to a claim statement initially made.

Condition: A statement that indicates a specific circumstance.

Consequence: Something that follows when a claim is true.

Effect: A result or outcome of a cause.

Effect-Cause: This code was used in the sickle cell anemia laboratory to indicate an intermediate

step within a series of cause-effect events. In such case any effect is the also cause of another effect until no further effects can be identified. Therefore it represents an effect and a cause at the same time.

Elaboration: Detailed information provided about a preceding statement. Students usually elaborated their claims and evidence.

Evidence: Piece information to support a claim, inferential statement. Evidence could be either empirical or theoretical. While observations can be evidence, unless they were explicitly used to back up a claim statement or another idea, they were considered observations.

Hypothesis: A tentative explanation, it is often a prediction of what will happen given the conditions and available information.

Generalization: A statement that presents a general truth, indicates that a phenomenon is always observed in the same way under defined conditions. In the context of this study, students' generalizations were usually based on theoretical information.

If/then reasoning: A pair of clauses connected together with the conjunction "if." Typically the first clause indicates a condition and second clause indicates an outcome based on the stated condition.

Inference: An inference is reasoning based on observation and experience. To infer is to arrive at a decision by reasoning from known facts. For instance, observing the movement of water from one environment to another through a semi-permeable membrane, one can infer about osmotic characteristics (i.e. hypotonic or hypertonic) of a solution.

Known fact: A piece of factual information known from the textbook.

Presentation: A clause that introduces a new idea or that defines a new context.

Observation: A statement that reports what is usually observed visually, but may include any sensory perception.

Reference to a chart: In the evolution laboratory, when students referred to the charts to support their ideas this code was used.

Religious/personal belief: In the evolution laboratory, when students expressed a non-scientific belief or a religious belief, this code was used.

Rebuttal of a hypothesis: In the evolution laboratory, when students denied a hypothesis this code was used.

Selection of alternative hypothesis: In the evolution laboratory, when students chose one of the alternative statements this code was used.

CHAPTER 4

RESULTS

In this chapter, findings from the data analyses are presented. The chapter begins with the meaning of explanations in students' views. This section addresses the research question one. The second section is about the characteristics of students' scientific explanations, which addresses research question two. This section represents findings from the six different science laboratory investigations and science letters. The most striking results of the data analysis were represented as assertions. The third section is on the nature of students' epistemologies related to scientific explanations and it answers research questions three. In the final section, the genre characteristics of students' explanations are presented. In the following sections, when I present quotes from student interviews or writings, sometimes I italicized students' words in order to get the readers attention to a particular point that I make.

The Meaning of Scientific Explanations for the Students

Students' understandings of the scientific explanations were mainly revealed by the interview data. Participants in this study were not explicitly taught about the nature of scientific explanations, nor were they given instructions to provide explanations in a particular way. However, prior to the data collection, in the pilot gummy bear activity, students were involved in a whole class discussion. In the discussion, students shared their opinions as to what counts as data, evidence, a claim and explanation. Students' opinions of the characteristics of explanations were written on the black board. The researcher's role in the discussion was of a facilitator. No binding definition of scientific explanation was asserted for the students. Nonetheless,

throughout the semester, the researcher and the teacher provided feedback regarding the plausibility of students' explanations, either verbally during their laboratory works as requested by students or as written comments on students' laboratory sheets.

Characteristics of Explanations in Students' Views

In the interviews, each student was asked to make a distinction between a claim, evidence and an explanation. It was easier for students to define claims and evidence, while they had a difficult time to present their ideas of explanations. Most of the students were successful in distinguishing between claim and evidence. However, scientific explanation remained a vague concept for many students. Students consistently indicated that a claim is what you think happened in the experiment. The majority of the students thought that evidence is the data or the proof you use to back up a claim or an idea. For instance, "evidence is sort of like the data you get from the labs, you use that so to speak evidence; evidence is something that you have so say to prove to somebody what happened" (John). A few students' understanding of evidence was not as clear as other students, for instance, "evidence is what you do in the experiment over and over...and see the answers you come up with whatever. Make sure always the same or whatever, and that will give you the evidence" (Macy).

Assertion 1: Three common attributes of scientific explanations were identified in students' views:

- a) Scientific explanations refer to exactness, reality, and truth.
- b) Scientific explanations are the final step of an experiment.
- c) Scientific explanations are based on data and evidence. Students rely on first hand observations but not on theories or causality.

Explanation as Exactness, Reality and Truth. When students were asked about their understanding of scientific explanation, they emphasized the following attributes: reality, actuality, clarity, exactness, and truth. For many students, explanation was the “real” thing, or it was the “exact” account of what happened or the “truth” of the matter. For instance:

“Explanation is telling *exactly* why it happened, how it happened, and *exactly* what happened” (Barbara); or “It is *actually* explaining what happened instead of... you *actually* find out the *real* answer” (Ben). Another student, Amy, also indicated that explanation tells us what actually happened in an experiment. “Explanations are just telling what *actually* happened. It is like facts.” In the following quote John indicated that explanations are close to the truth. “...explanation is so, it is telling you, if your claim is right, because you use all the data from the experiment, saying what is happening, how is it happening.... So, explanation is pretty, really close to *truth* so to speak.”

These findings suggest that students appreciated the importance of scientific explanations in the scientific process. Students attached words to scientific explanations that represent some degree of rigor, such as exactness, truth, and reality.

Explanation as the Final Stage of an Experiment. Some students developed a continuous view of the claim-evidence-explanation sequence in which explanation is viewed as the final stage where one concludes. For example, Kimberly said “An explanation is either explanation of your claim or explanation of outcome, and the outcome is what happened after you do all the experiment.” Nikki was another student who thought that explanation is given at the end of an experiment. “Why it happens after the end of the experiment. You did it and your explanation is why it happened.”

In another quote, Tracey indicated that explanation gives an account of what happened in an experiment. “That [explanation] is the one it shows, what happened in the experiment. It is pretty much like the whole thing, explanation of what happened.”

A majority of the students made a connection between a claim and evidence. Students held similar views of claims and of evidence. On the other hand, different perceptions of explanations were revealed in students’ interview responses.

Students’ views of explanations from their own words is provided in Appendix C. Of the 13 students interviewed, five students indicated that evidence or data is needed to make an explanation. Four of the students indicated that an explanation shows how something happened. Most students could not give a clear definition, but they described what could be a scientific explanation. For example: “You are just looking data from the experiment and playing out and showing the person this is how it happened” (Allison).

Explanation as Related to First Hand Experience. One interesting finding was that students perceived the scientific explanations as the explanations of events that are specified in time and place. Implicit in students’ responses was that explanation is given in the aftermath of an event or investigation. Thus, students represented a view of explanation that is specific to the experience of the person who explains. A majority of students simply expressed this idea when they refer to scientific explanation as a detailed account of what happened in the experiment or investigation. None of the students represented a view of explanation that may refer to the events or phenomena that can be generalized and non-specific in time and place or to phenomena that can be commonly observed, for example adaptive features of organisms.

The explanations of generalizable events often entail articulation of a theory or principle, which is not necessarily an integral part of student experience or knowledge. However, students

understanding of explanation reflected an empiricist view in which explanations are given after processing of data and evidence collected in the experiment or investigation. The students conceived of explanations as an authentic process where the explainer constructs her explanation from the available first hand information and prior knowledge. Students' understanding of scientific explanations may have been influenced by their participation in the current study. Because students always did an investigation or experiment before they write an explanation, they associated their scientific explanations with data and evidence collected so that often their explanations included a detailed account of what happened in the experiment.

The analyses of concept maps that students made during the interviews also supported this view. Table 4.1 represents the six major features of scientific explanations as defined by students. All of the categorical names were the actual words used by the students, with the exception of theory/background. Some of the categories perhaps overlap, for instance data and evidence. Only one student stated theory. However, there were other students who used expressions that conveyed similar meanings. Students used the following expressions: facts, prior knowledge, research (what refers to background information in the laboratory sheets), and things already known. Students consistently referred to data, evidence, and experiments.

Table 4.1

Characteristics of scientific explanations as defined by students during the interviews

Category	Number of Responses
Data	9
Background information/Theory	8
Hypothesis	7
Experimentation	6
Evidence	5
Observation	4

The following dialog between the researcher and Laura shows Laura's interpretation of scientific explanation as related to first hand observations of her own experiment (L: Laura, D: Researcher).

L: You have to have research and data, you take known evidence, things people already figured out, whatever you are doing. And your own ideas things you might happen. Like [inaudible] some hypothesis and stuff like that. And you have to do the experiment where all kind of different things, so you can prove right or wrong whatever you are thinking.

D: How does experimentation help?

L: Well, when you come up with a scientific explanation you have to do an experiment. You have to use experimentation, you have to use different things, just to prove right or wrong what you're thinking.

One interesting finding was that students did not mention anything about causality in their concept maps and interviews, except for two students who said that explanation should tell why and how something happens. Theories were also scarcely mentioned. On the other hand, students often cited what is most easily accessible to them such as data, evidence, observations, things that are actually produced as a result of their interactions during the laboratory investigations.

This finding recalls Veel's idea of discursive shifts (1997). Veel makes a distinction among three domains of school science discourse: procedures and procedural recounts, explanations and reports, and expositions and discussions. In the practice of school science shifts occur between these discursive domains, and focus of the teaching emphasis changes. Veel indicates that if the focus is on practical skills, procedures and their recounts emphasized more

than explanations, reports, expositions and discussions. If the focus is on social issues and impacts, then expositions and discussions are emphasized more. While the focus of emphasis changes from one domain to another, Veel contends, shifts occur between the respective genres of those domains, for instance, a shift from procedural account to explanations could occur.

Students' Scientific Explanations and Daily Life Explanations

Assertion 2: The main difference between students daily life explanations and scientific explanations is that students think evidence is needed to back up scientific explanations while daily life explanations often do not require evidence.

During the interviews students were asked to compare and contrast their daily life explanations to scientific explanations. About half of the students indicated that their daily life explanations and their scientific explanations are similar; in other words, they did not articulate any specific difference between the two. The other half of the students thought that scientific explanations are different from daily life explanations in that details, evidence and scientific information are provided in scientific explanations, while evidence is not necessarily for daily life explanations. For instance in the following excerpt, John tells the difference between scientific explanations and daily life explanations:

Yeah, I would have to say so. Because if you're just talking to a friend, you know, you don't have to describe anything in detail or you know, you don't have to have proof for it, pretty much just believe you for what you say. But you know in science, you have to be very detailed, you have to have proof to back up what you say, because there is no way of telling you, if you are right or wrong [inaudible], proof. So it is different, I have

to work more on, trying to figure out the details and having proof to back up what I am saying for explaining something for you know science.

Another student, Laura, also made a similar point. Like John, Laura thinks that scientific explanations should be backed up with evidence.

They are similar, but the difference is in daily explanations you don't have as much as evidence to back up what your doing, you don't have as much, so you don't go into as much depth as you are doing your scientific explanations. Because when it comes to scientific explanations you have to have evidence to back it up. So people believe it.

The students who thought that scientific explanations and daily life explanations are similar did not provide a strong justification for their opinions. However, one student who initially thought that there is not too much difference between scientific explanations and daily life explanations changed his mind when he was provided with an example by the researcher.

Characteristics of Students' Explanations As Interpreted By the Researcher

In this section, first, the guiding literature on scientific explanations will be briefly reviewed and then findings for the six different laboratory investigations will be presented.

The literature on scientific explanations offered different approaches to classify scientific explanations. However, in science education there has been limited attempt to classify the different types of scientific explanations. Veel (1997) distinguished six types of explanation genres in school science (Table 4.2).

Table 4.2

Explanation genres in school science according to Veel (1997, p.172)

Genre	Social Purpose
Sequential explanation	To explain how something occurs or is produced-usually observable sequences of activities which take place on a regular basis
Causal explanation	To explain why an abstract and/or not readily observable process occurs
Factorial explanation	To explain events for which there are number of simultaneously occurring causes
Theoretical explanation	To introduce and illustrate a theoretical principle and/or to explain events which are counter-intuitive
Consequential explanation	To explain events which have a number of simultaneously occurring events
Exploration	To account for events for which there are two or more viable explanations

The range of scientific explanation genres defined by Veel represents types used in textbooks. In the current study, not all of the explanation genres defined by Veel were observed. With some modifications to Veel's categorization, connections between the laboratory investigation tasks and the type of scientific explanations they render are made. These connections are shown in Table 4.3.

Table 4.3

Types of explanations observed in the current study

Laboratory Investigation	Explained Phenomena	Type of explanation
Acid Rain	Explanation of how acid rain interferes with the seed germination	Exploration
Osmosis	Explanation of water movement in and out of an egg under different conditions	Theoretical
Genetics	a) Explanation of the causal process involved in development of sickle cell anemia disease.	Causal/Sequential
	b) Explanation of how (S) alleles are maintained in places where malaria disease is common	Causal/Theoretical
Evolution	a)Explanation of whether human and apes have common ancestor or humans evolved from the apes	Theoretical
	b) Explanation of whether humans and	Theoretical

	chimpanzees have a common ancestor	
Fungi	Explanations of different amounts of fungi growth under different conditions	Exploration
Leaf Stomata	a) Explanation of the different number of stomata found on the different surface area of a leaf. b) Explanation of how guard cells respond to hot and dry conditions	Exploration Exploration

In the context of the current study three types of explanation were distinguished: exploration, causal/sequential explanations, and theoretical explanations. Explorations were used in the sense that Veel (1997) defined in his categorization. When more than one viable explanatory account was available, the type of explanation in that unit was called exploration. These types of explanations were observed in the acid rain, fungi, and leaf stomata labs. In the fungi unit laboratory, for instance, for many groups, there was more than one way to explain the different results. In the leaf stomata laboratory students could provide different reasons for leaves having more stomata on one side than the other. Causal/sequential explanations are combination of what was defined by Veel (1997) as causal and sequential explanations. These types of explanations include causal relationships and/or a sequential relationship between the events or the stages of a phenomenal process. The theoretical explanations are those given by on the basis of theory. In other words, they are explanations given through theory articulation (for instance, explanations in the osmosis unit laboratory).

Unlike theoretical explanations or causal explanations that are more conclusive in nature, exploration type of explanations is more like approximations of the best explanation. In exploratory type of explanations, students often make hypotheses through inferring. What is known as “inference to the best explanation” in the philosophical literature, perhaps matches with my intention here. Lipton defines “inference to the best explanation” as follows:

“According to the model of inference to the best explanation, our explanatory practices guide our inferences. Beginning with the best evidence available to us, we infer what would, if true, provide the best explanation of that evidence” (Lipton, 1991, p.1). By making inference, in a way, we choose the best hypothesis that explains the data or the evidence.

One caveat here needs to be made: the three types of scientific explanations mentioned above are not necessarily mutually exclusive. For instance, students can make explorations while they are constructing a theoretical explanation or a causal explanation. Nonetheless, the intention of this categorization is to identify the nature of explanation tasks on the basis of the most significant components involved in it. For instance, when an appropriate presentation of the osmosis theory along with supporting data and evidence is sufficient to give a good explanation, then that type of explanation is considered as a theoretical explanation. Or as in the leaf stomata laboratory, when students’ hypotheses from their knowledge of the structure and function of guard cells/stomata suffice a good explanation, they are considered a type of exploration. Even though students used some theoretical (textbook) information as a basis for their hypothesis, their mental derivations represented ideas beyond the textbook information. When hypotheses or inferences attempt to explain beyond what is already known as facts, explanations are considered explorations instead of theoretical explanations.

The framework that Veal (1997) provided helped me to see various types of explanations, and guided my initial coding. It offered an overarching categorization of explanation types. However, this categorization’s help to resolve the intricacies of coding has been limited. I could expect to see certain types of coding in certain types of explanations. For instance, one would expect to see causes in causal explanations or hypotheses in the exploration type of explanations. However, the whole process of coding could not be finished just with the help of a framework.

The coding could be best understood by considering the specific contexts of explanation questions. Although Veel's (1997) schema provided a more universal view of categorization, analyses in each laboratory investigation demanded more scrutiny to understand the students' explanations, which resulted from specific questions within specific contexts. Since each explanation question was situated within a context, codes were not equally distributed, and some codes were observed in only one unit. For instance, in the evolution laboratory investigation, the explanation question was very unique in that students were given two choices of ideas, and they were asked to explain which idea or statement was best supported by the theory of evolution. The explanation task directed students to choose one of the ideas and to support or justify their choices. Therefore, the coding in this unit reflected the nature of explanations task and its specific context. The other laboratory investigations also had their specific contexts.

In the following subsections, analyses of students' written explanations are provided for each laboratory investigation unit.

The Acid Rain Laboratory Analysis Results

The purpose of the acid rain unit was to observe the effect of acid rain on seed germination. For this purpose, students observed the effects of varying vinegar solutions and a control solution (water) on growing bean seeds. The following question was asked of the students:

Explain specifically how acid rain interferes with the seed germination process. You may use any of the following resources: everyday knowledge, notes from science class, research information at the beginning of this laboratory, and the attached information sheet on acid precipitation and the environment.

The explanation requested in this unit was an explanation of an unobservable phenomenon. The laboratory investigation undertaken did not allow students to observe the actual process in which acid rain affects the seeds. Nonetheless, students were able to observe what happened to bean seeds when they soaked in the varying vinegar solutions. Perhaps the explanation question in this unit was one of the most difficult questions asked of students in this study because first hand experience alone did not help students to explain. Therefore, students were encouraged to use all other possible external sources including one page from a college level textbook about acid rains and their prior knowledge.

In the text, the following section was the most relevant section for students' interest: "strong acidity can break down the molecules of living organisms. And even if the molecules remain intact, they may not be able to carry out the essential chemical processes of life at very low pH" (Campbell, Mitchell, & Reece, 1997). In this unit there was a low rate of turning in laboratory sheets. Only eight students' responses were analyzed in this unit.

Assertion 3: The analyses of the students' explanations showed that students were not successful at reading the extra material, personalizing this knowledge, and presenting it in their own words. This assertion has been also supported by data from the sickle cell anemia laboratory, which will be presented in the following section.

Only two students referred to the textbook explanation given in the reading material. One of these students, Ben, gave only a sentence long explanation, while the other student, Anthony, provided more information with his own thinking. These explanations follow:

"Acid rain affects the seed germination process by breaking down the molecules in a living organism¹" (Ben).

¹ All of the quotes from students are verbatim; quotes can have grammatical mistakes or scientifically incorrect information.

“The acid breaks down the seed coats and makes the seeds soluble with the acid. It breaks down the molecules of living organisms” (Anthony).

Table 4.4 shows the codes that were identified during the analysis of students’ responses.

Table 4.4

Emergent codes from the analysis of acid rain laboratory explanations

Codes	Examples	Number of Occurrences	Number of students (Out of 7)
Claim	“The acid breaks down the seed, makes the seed soft.”	7	6
Consequence (of a claim)	“Thus, [it] doesn’t allow the seed to continue its growth process and germinate.”	3	3
Elaboration	“The acid makes it difficult for seed to grow, it changes completely.”	3	3
If/then reasoning	“If you have a weak acid, then you will have a larger number of seeds.”	2	2
Generalization	“The stronger the acid, the less number of germinated seeds.”	1	1

In their responses, students often started their explanations making claims by inferring how acid rain interferes with seed germination. They then provided further information about the effects of acid rain, elaborating on the possible results of this effect. For instance, “The acid breaks down the seed, makes the seed soft. Thus doesn’t allow the seed to continue its growth process and germinate. The acid makes it difficult for the seed to grow, it changes completely” (Barbara).

In her response, Barbara, first made an inferential claim about how the acid affects seeds. Then she developed her explanation around this idea. Another student, Sandy, developed her explanation in a similar way, making a claim first and then developing the explanation based upon that claim. However, her reasoning in her explanation goes in a different direction than the intended one.

“Acid rain basically kills the seeds, therefore making it impossible to germinate. If the seeds die, then that eventually kill out the forest or whatever location it may be, because without seed germination you have no plants therefore no forests” (Sandy).

Some students represented intuitive thinking in their explanations. For instance, “The acid breaks apart the water molecules taking away the oxygen in the water, without oxygen the seeds cannot grow, but liquid will begin to break apart the seeds and make them softer” (Laura).

In her explanation, Laura represents information that was not found in either the laboratory sheets or the given textbook reading, but she tried to guess about the effect of acid rain on a molecular level.

Summary for the acid rain laboratory. In this unit, students had to explain a phenomenon that could not be readily observed. Therefore, students had to use all the theoretical information available, as well as their personal experience and everyday knowledge to explain the phenomena. Analysis showed that most students do not read the complementary reading material, or they have problems internalizing the knowledge they read. However, some students presented a consistent way of explaining starting with a claim and constructing the explanation that justifies their claims, although their explanations may not represent the scientific view.

The Osmosis Laboratory Analysis Results

In the osmosis unit, the explanation task required students to articulate the theory of osmosis. The explanation question was the following:

Explain specifically why the water moves in and out of the egg, when the egg is put in different solutions, such as vinegar, syrup or water? Why in some cases does the egg take in water and in other cases it loses water?

Assertion 4: Most students made explanations of osmosis based on specific conditions but not based on general rules and deduction. This correlates with their understanding of explanation as related to first hand observations, data, claim and evidence.

The analysis showed that most of the students were not able to give an explanation based on the theory of osmosis. Students often relied on their first hand experience in their explanations. They often made inferences from their observations about whether a solution was hypertonic or hypotonic. However, many students did not use the terms properly; these students were confused about what to call as hypertonic or hypotonic among a solvent, solution, and a solute.

Table 4.5

Emergent codes from the analysis of osmosis laboratory explanations

Codes	Examples	Number of occurrences	Number of students (Out of 14)
Evidence	"It has a low water concentration and high solute concentration."	70	14
Inference	"Syrup is hypertonic."	23	9
Presentation	"When the egg was in the vinegar"	11	7
Generalization	"If the pressure inside the egg is less than the pressure outside, water will move in like when we put in water"	4	2

As seen in Table 4.5, the most common code was evidence, which included students' observations and data. Student often reported their descriptions of osmosis, for instance, "the shell was eaten away."

Often times students presented their evidence as premises for their inferences for instance, "in the syrup, it was hypertonic [sic], because it (egg) deflated and pushed the water back out into the jar." In the above statement, the second clause is considered evidence since it backs up the first clause, which was considered as an inference. In order to make an inference

about whether a solution is hypertonic or hypotonic, a student, first, must know the meaning of terms hypotonic and hypertonic (an understanding of osmosis principle). Second, he or she must have an experience with that solution to gather evidence. Using the theoretical information and the evidence, then students can make inferences about the osmotic nature of a solution.

Most of these students' inferences were about identifying what type of osmotic solutions vinegar, syrup and water were. For example:

Vinegar is hypotonic. It has a high water concentration a low solute concentration, so water moved in the egg. Syrup is hypertonic. It has a low water concentration and high solute concentration, so water moved out of the egg. Water is hypotonic like vinegar; it has a high water concentration and low solute concentration, so water moved into egg (Elizabeth).

The example above is the entire response from Elizabeth to the explanation question asked. In this explanation Elizabeth was making inferences (a conclusion drawn from evidence or reasoning) about the hypertonic or hypotonic nature of the solutions. Based on her observations or evidence, for instance observation of the movement of water, Elizabeth was able to identify the osmotic characteristics of solutions. However, in Elizabeth's explanations it is implicit that a hypotonic solution will diffuse to the side that has less water, in our case, inside the egg. The explanation was not constructed on the basis of a general rule, but on specific conditions. Most students' explanations were organized in a similar way to Elizabeth's, giving an account of three different cases for vinegar, syrup and water.

Only two students made generalizations in their explanations. These students inducted rules from their experience. In the following example, Bart constructs his explanation based on a general rule.

If the pressure inside the egg is less than the pressure outside, water will move in like when put in water-hypotonic. If the pressure inside the egg is more than pressure outside, water will move out like when we put in vinegar and syrup-hypertonic. When in the water, the egg result was cytolysis and the pressure up. When in the vinegar and syrup the egg result was plasmolysis and pressure down.

Unlike Elizabeth's explanations, which were specific for each of the three experiment conditions, Bart made generalizations about what would happen under certain conditions and he supported his ideas with examples from his laboratory experience.

Another example of generalization was in Barbara's explanation:

The water flows to whichever has less of it. In the case of the vinegar, water increased and causing hypotonic solution. In the syrup, the water decreased causing a hypertonic solution. In the water, water decreased causing a hypotonic solution.

Although Barbara was able to induct a rule, her use of scientific terminology was not proper, and her sentences were ambiguous. For instance, it is not clear wherein the water level increased or decreased, inside the egg or in the solution. It is also confusing that hypotonic or hypertonic properties are caused by the change in water levels.

There were other students who had similar problems with appropriating the osmotic terms. The following quotes from different students represent students' difficulty in using these terms.

Allison: "When the egg was in the jar, the water moved in causes it to be hypotonic."

Anthony: "The egg and syrup has hypertonic solution."

Nikki: "In the syrup it was hypertonic..."

Macy: "When the egg was removed from vinegar, I observed that it was hypotonic."

It was an interesting finding that none of the students mentioned the term “osmosis” in their explanations. However, students frequently used terms related to osmosis, such as hypertonic and hypotonic. One student also used plasmolysis and cytolysis in his explanations. Although students did not explicitly talk about the osmosis principle, they represented a tacit understanding of the principle.

Except for the students who made generalizations, other students’ explanations did not fully explain the reason why the egg absorbed water or lost water. For instance, one student said, “The syrup did not go into the egg, because it was thick substance.” In this explanation the student implies that syrup is denser than the liquid inside the egg. However, it does not further explain how the density gradient affects osmotic pressure.

The interview data confirmed that theories play little role in students’ explanations. Perhaps students do not realize and appreciate the function of scientific theories, even though they have an obscure understanding of the physical rules involved in the process. For instance, in the following excerpt, Noah cannot recall the osmosis principle and his explanation is limited to his observations. However, when he was encouraged to make a generalization he was able to induct a rule.

D (Deniz): So can you tell me why it [the egg] got swollen in the water, but not in the syrup?

N (Noah): Because, the egg absorbed water and then, in the vinegar it ate the shell away, like it took the water out of it.

D: Those are right, but how did egg absorb the water? Why, I mean?

N: (Pause)

D: Can you think about any scientific principle, or rule that you can apply to this situation and explain the case?

N: Not at the top of my head, not really.

D: Is there any principle here? Like, if we do this experiment over and over again, do you think we would get the same results?

N: Yeah,

D: So can we make generalizations?

N: Hmm, hmm.

D: So what would be your generalization here?

N: The egg will always absorb the water in similar situations.

In another example, Brett also cannot recall the osmosis principle but he can make a generalization when it is asked.

D: So, why in water it absorbed the water, but not in the syrup?

B: In the syrup, wouldn't be able to move easily. In the water, it could. It was able to move, like diffuse. It was able to umm....in the syrup it is more of thick, so in the water is more liquid. So it was able to sucked in the egg, when the egg cannot suck up syrup, it is all..., it was not really [Inaudible]. It was just...

D: Can you think of any scientific principle or law that applies here?

B: I don't remember... [Inaudible].

D: This is not called a law, but I think may be principle.

D: If you do this experiment again, would you expect the same results again?

B: Yeah, I guess.

D: So can we make a generalization?

B: Hmm, hmm

D: So what would be the generalization then?

B: That will be, egg will act, like umm, be able to do just like same. It is like a constant. If you use the same stuff it is not going to be different.

The results of this unit suggested similar type of reasoning that was found in the literature. Researchers in the field suggested the existence of different developmental stages in students' explanations. One model of this was Driver et al.'s (1996) three-stage reasoning: phenomena-based reasoning, relation-based reasoning and model-based reasoning. Similar categorization was also suggested by Mayer (1992). Most of the students' explanations were in the category of phenomenon-based reasoning in which explanations are provided as descriptions.

There were many students who expressed their explanations with vocabulary from their daily life as opposed to scientific vocabulary, for instance, describing the syrup as thick.

Summary for the osmosis laboratory. Using their observations and evidence, students were successful in making inferences about the different physical natures of the solutions. Students were successful in identifying different solutions (i.e. hypotonic or hypertonic) as causes for the water movement, and they were successful identifying the effects (e.g. swollen egg). However, most students' explanations did not elaborate on how different solutions affect the osmotic pressures. Although most students made the distinction between hypertonic and hypotonic solutions correctly, they did not support their explanation with a principled idea, and their explanations were case-specific. Only two students constructed their explanations based on a generalized rule.

Sickle Cell Anemia Laboratory Results

In the sickle anemia laboratory two explanation questions were asked to students.

- a) Explain the cause-effect mechanism by which a single base mutation on a DNA strand can cause sickle cell anemia disease.
- b) Explain how sickle cell (S) alleles are maintained in places where malaria disease is common (Hint: Use the attached reading).

The first question was related to the cause-effect mechanism involved in the development of sickle cell anemia disease. The basic information to answer this explanation questions was given in the pre-laboratory activities. Before the wet laboratory started, students were involved in a series of activities on their laboratory sheets. Students were given a DNA sequence that carried a sickle cell anemia mutation on it, and they were asked to write the complementary DNA chain and mRNA chain that carries the mutation. In the background section, students were also provided with the information about how defected hemoglobin protein molecules cause changes that yield sickle shaped red blood cells that could eventually threaten a person's life.

The second question required students to read an attached text to answer the question. This question was perhaps one of the most difficult explanation questions, because students had less relevant laboratory experience with the subject.

Assertion 5: Students have difficulties in identifying the cause-effect relationships in sequential events.

The analysis of explanations given for the first question showed that students could identify the initial cause and the ultimate effect in a series of cause-effect sequence. Students, however, were not successful in identifying the intermediate steps involved in the process. Figure 4.1 represents a series of cause-effect relationship in developing sickle cell anemia disease.

Most students correctly identified the first cause as a mutation on a single nucleic acid of DNA. However, the majority of students did not talk beyond the changes in the amino acid sequence of hemoglobin protein. Only two of the students mentioned the changes in the structure of hemoglobin protein. For instance, in the following quote Elizabeth gives her explanation: "The DNA is mutated [cause] which causes the complementary DNA to be defective [effect-

cause]. This causes a defect of the amino acid sequence [effect-cause] which leads to a defect in proteins and hemoglobin [effect].” The information in brackets was added to show coding.

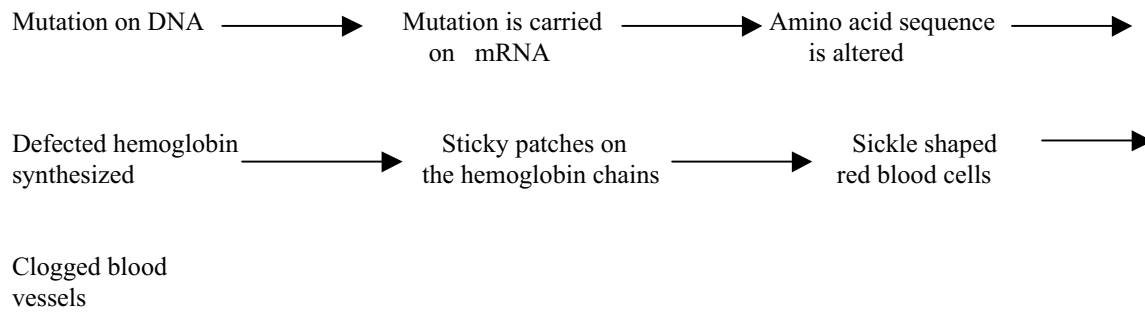


Figure 4.1

Cause-effect mechanisms involved in developing sickle cell anemia disease

Another student, Noah, successfully identified the mutation and subsequent changes in the amino acid chain. However, his explanation did not provide further details about how the change in amino acid sequences results in defected protein structure.

“The cause is the one base difference [cause]. Although it is only one letter, it still makes a big difference [evaluation]. The effect that one letter has on the person is the amount of glutamic acid [effect]. In a normal person, there are two glutamic acids [elaboration], but in a sickle celled person it is replaced with valine [elaboration] which makes them sick [cause]” (Codes are added).

In the above example, Noah, does not explain how the replacement of glutamic acid with valine changes the structure of hemoglobin protein. As seen in the above quote, students’ explanations

also revealed some misconceptions. Noah seems to conceptualize the mutations of sickle cell anemia disease in only one cell or one amino acid sequence. However, once the mutation happens it affects all the hemoglobin proteins coded by the mutated gene sequence.

Most students were not able to provide a casual account of successive events. Among 12 students who answered the first question, seven of the students identified only one pair of cause and effect. These students indicated that there was a change in the DNA sequence. The effect identified by these students was the sickle cell anemia disease. In other words, these students identified the first and the last steps of a cause-effect mechanism. The intermediate steps of the process were not mentioned by these students.

For instance, in the following quote the student tells about the initial cause and the ultimate effect not mentioning the intermediate steps. “Because when that single chromosome out of 3 billion broke or was different [cause], it messed up the genetic code, which caused it to form a disease [effect]” (Ben).

Two students identified one cause, but these students only talked about a change in the DNA they did not provide any other information. For instance: “The replace on glutamic acid w/valine [cause]” (Allison).

One student identified one cause and three consecutive effects of that cause. The explanation of this student (Elizabeth) was provided in previous paragraphs.

Two of the students did not talk about causes. These students understood the questions in a different way.

“If either parent is a carrier or a known infected, then chances are that offspring will be infected also. If both parents were B, then the child won’t have the disease. If both parents are P, then the child will definitely be infected with the disease fully” (Barbara).

The codes that are resulted from the analysis are presented in Table 4.6. As seen in the Table 4.6, the most common codes were cause and effect. The code cause referred to the first mentioned cause in a student's explanation. The code effect refers to the last mentioned effect in the explanations. All other causes and effects that students identified in the same continual process are called effect-cause, because effect of an event is the cause of another effect. The effect-cause codes were seen only in Elizabeth's explanation. An example of student explanation with only one cause and effect will be Anthony's: "Only one single nucleic acid is changed in the DNA that changes regular DNA to sickle cell."

Table 4.6

Emergent codes from the analysis of the first explanation question of the sickle cell anemia laboratory

Codes	Examples	Number of occurrences	Number of students (Out of 12)
Cause	"Only one nucleic acid is changed in the DNA..."	12	11
Effect	"That changes regular DNA to sickle cell."	10	10
Effect-Cause	"which causes a defect of the amino acid sequence"	3	1
Elaboration	"In a normal person, there are two glutamic acids, but in a sickle celled person it is replaced with valine..."	7	4
Presentation	"The cause effect mechanism in DNA is like."	3	2
If/then reasoning	"If either parent is a carrier or a known infected then the child won't have the disease"	3	3

After cause and effect another common code was elaboration in students' explanations. When students elaborated their ideas they provided more detailed information about the previously stated idea. For instance:

Because when that single chromosome out of 3 billion broke or was different it messed up the set genetic code which caused it to form a disease. Because it altered the code

which was supposed to happen. In other words it got the wrong directions and coding (Bart).

In the above example, after proving a cause, Bart elaborates on the change that happened on the DNA.

Student explanations also included condition statements. Those sentences were identified with “if” clauses and they were usually followed by successive result statements. For instance: “If both parents are P, then the child will definitely be infected with the disease fully. The code presentation is used when a student introduced a new idea to the reader or when the statement did not serve any specific purpose rather than bringing the reader’s attention to a particular topic or idea.

The second explanation question in the laboratory required students to read an extra page of reading attached to the laboratory sheet (See Appendix B). Students had difficulties in reading and interpreting the texts. Nine of the students answered this question. Two of the students copied their answers directly from the text, while other students tried to explain in their own words. Most of these explanations did not contain sufficient information to answer the explanation question. In the quote below, Anthony attempts to answer the question, but he fails to provide necessary details.

“People in Africa developed a resistance to malaria and sickle cell because they have AS genotype. People with an AS genotype are carriers of sickle cell and pass it along to offspring.”

Anthony understands that heterozygous genotypes are somehow more advantageous, and since they are carriers of disease they pass along their genes to the next generations. However,

his answer does not consider other genotypes, and does not explain how heterozygous genotypes are favored.

The following explanation is from Elizabeth. Unlike Anthony, she considers three different genotypes and eventually justifies her explanation.

The AA will probably die from malaria. The SS will die from sickle cell. But in an area where there is AS, the S is maintained because AA are little in population; SS are little in population b/c they die. AS remains.

Using the available information that homozygous genotypes (AA and SS) will die from malaria or sickle cell anemia disease, Elizabeth infers that AS genotypes will remain in the population. But her explanation does not tell why individuals with AS genotypes survive.

In the next example, Macy's first sentence is copied from the text; she then tries to expand this idea in her explanation.

The S allele confers a survival advantage on people who have 1 copy of the allele, and therefore the harmful S allele is maintained in the population at a relatively high frequency. In a specific region a carrier passes the disease and they pass it to their children and so on through the generations. This spreads over the region b/c they basically stay in that area. If each carrier moved around the world then it would spread, but they don't. Therefore it maintains in that specific area and spreads. Malaria is common worldwide b/c it is caused by mosquitoes but sickle cell passes (Macy).

As in Macy's explanation, many students tried to build upon information given in the extra reading text. Although Macy represents good thinking her explanation does not tell why the S allele confers a survival advantage. Perhaps, the second explanation question addressed a phenomenon that was difficult to conceptualize for students, considering the lack of practical

experience or any visual aid material that would help them to better understand this phenomenon.

Summary for the sickle cell anemia laboratory. Both explanation questions in this unit were about unobservable phenomena. Unlike the osmosis unit, students did not have first-hand experience with the phenomenon. This may have affected the length and the quality of their explanations especially when students did not refer to authoritative sources. When students are working with tangible objects they can more easily make sense of them. Students seemed to have difficulties understanding phenomena at the molecular level. Only one student could provide an explanation that involved more than one pair of cause-effect relationships. Overall, the results suggested that students have difficulties in making causal explanations of complex biological phenomenon. Findings also suggested that students have difficulties in reading and understanding explanatory scientific texts.

The Evolution Laboratory Analysis Results

Evolution is the unifying theory of biology, and it is the most overarching theory in biology. Therefore, an understanding of evolution theory is important for students to be successful in biology. Unfortunately, many misunderstand evolution. One purpose of the evolution laboratory was to demonstrate the relationship between humans and ape groups based on the DNA sequence similarities. The evolution laboratory was intended to show that humans and apes have a common ancestor, unlike the misconceptual understanding that humans evolved from the apes. However, some students' personal beliefs were barriers for them to understand scientific view of human evolution.

In this laboratory, using different color paper clips students simulated a small section of hemoglobin DNA for humans, chimpanzees, gorillas and a common ancestor. After comparing

the DNA base similarities among those species, students were asked to create a morphological tree that is best supported by the data. The explanation questions required students to choose one of the alternative statements about human evolution and to support their answers with the evidence they collected. The explanation questions were following:

1) Based on the hypothesis that your data best supported, which of the following statements is most accurate? Explain your answer in a short paragraph. Build your explanation upon the data and evidence you collected, and use the morphological tree model to support your explanation.

a) Humans and apes have a common ancestor.

b) Humans evolved from apes.

2) Using the same instructions on question 3, which one of the following statements is most accurate?

a) Chimpanzees are the direct ancestors of humans.

b) Chimpanzees and human have a common ancestor.

Assertion 6: Students relied on both evidence and their personal beliefs in their explanations in the evolution unit.

Nine of the students who responded included evidence in their explanations. These students explained the idea of common ancestry based on the similarities in DNA sequences. On the other hand, three students who did not use evidence in their explanations and two of the students who used evidence clearly or implicitly indicated that they do not believe in evolution theory. These students either denied the theory of evolution or they used expressions like “scientist would say” or “scientists believe” instead of telling what they think as answers for the questions. Students who denied evolution did not mention anything about the DNA base similarities between the

chimps and humans or ancestral relationships represented in morphological trees. These students questioned or challenged the ideas presented in the explanation questions. They also wrote some of the words underlined or with capital letters to emphasize the strength of their opinions. In the following quote, Kimberly denied the theory of evolution, and instead of answering the explanation question she shared her personal beliefs. The quote is her response to question one:

Humans and apes have no relations what so ever. I cannot agree with so called “theory” of evolution. I was and will always be taught to believe in creation. The older I get, and the more I read the Bible. I have formed my opinion. My opinion and religious beliefs are too strong to believe in something so absurd.

Although Kimberly denied the theory of evolution, in her explanation to the second question, she said species evolve or undergo adaptations. Her explanations may represent the difficulty she had in reconciling her personal beliefs and scientific knowledge. Kimberly continues in her explanation to second question:

Again, neither one is accurate. There is no documented evidence, because there is no truth behind evolution. I believe, however, that a certain species can evolve and adapt change. I understand you are not trying to change our opinions, but my opinion is that there is no such thing and if we evolve from apes, why are there still apes?

There were also other students who were not as open as Kimberly to present their personal views, but still suggested their personal beliefs. For instance, in the following quote Laura gives her explanation in terms of possibilities and implicitly indicates that she does not agree with the scientific view of human evolution: “They [humans and chimpanzee] had some of the same traits, so they might have come from a common ancestor, at least that is what scientists believe.”

An example of explanation based on evidence is Macy's explanation. Macy constructs her explanation based on the morphological tree she drew during the experiment. Macy's explanation is seen on Figure 4.2

In her explanation, Macy presents a good understanding of DNA base similarities and morphological trees.

The results of the coding in this unit are shown on Table 4.7. The eight most frequent codes are included in the table.

Table 4.7

Emergent codes from the analysis of evolution laboratory explanations

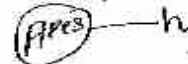
Codes	Examples	Number of Occurrences	Number of students (Out of 12)
Evidence	"Because they are so close in the DNA- only five differences the humans are closer to the chimp than the gorilla."	25	9
Selection of alternative hypothesis	"I think that humans and apes have a common ancestor."	17	9
Religious/personal beliefs	"I cannot agree with the so called 'theory' of evidence."	4	2
Questioning or challenging the ideas presented in the questions	"If we directly came from chimpanzees, why aren't our DNA is identical."	4	2
Rebuttal of a hypothesis	"...but chimps didn't evolve from humans"	4	2
Reference to a chart	"If humans evolved from apes it'd be figure 2 instead of figure 1."	3	3
Elaboration	"Their DNA strands are closely related" [After the statement "because they had fewer differences."	3	2

- 3) Based on the hypothesis that your data best supported, which of the following statements is most accurate? Explain your answer in a short paragraph. Build your explanation upon the data and evidence you collected, and use the morphological tree model to support your explanation (15 points).

- a) Humans and apes have a common ancestor.
b) Humans evolved from apes.

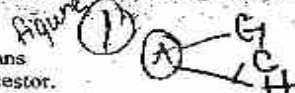


Based on our gathered info, humans & apes have a common ancestor. Their DNA sequences are similar but differ in ways. The similar DNA shows that apes & humans have a common ancestor. Humans couldn't have evolved from apes b/c they're different branches w/ same ancestor. If humans evolved from apes it'd be Figure 2 instead of Figure 1.



- 4) Using the same instructions on question 3, which one of the following statements is most accurate? (15 points).

- a) Chimpanzees are the direct ancestors of humans
b) Chimpanzees and humans have a common ancestor.



Based on the data chimpanzees & humans have a common ancestor but chimps. didn't evolve from humans b/c in the tree humans & chimps have different branches. If chimps evolved from humans they would be on the same branch (instead of Figure 1 it would be Figure 2 for chimps being direct ancestors).

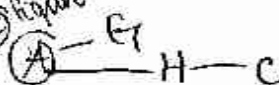


Figure 4.2
Macy's explanations in the evolution laboratory

Every student who responded to the explanation questions chose the correct statement to start with their explanations. However, students who denied evolution and students who implicitly or explicitly rejected the idea of evolution did not use evidence in their explanations. Therefore, the numbers represented in Table 4.7 are not equally distributed among students. However, the table represents students' thinking related to a certain type of explanation question in which the learner selects one of the alternative hypotheses available and justifies his/her choice with evidence. Elizabeth gave another example of explanation supported with evidence:

Humans and apes have a common ancestor. The morphological tree doesn't support evidence of humans evolving from apes; however it does support the evidence that they have a common ancestor. I figured this out by studying my data. When I look at my morphological tree, I see that gorillas, chimps and humans all have a common ancestor, but the humans and chimps are more closely related.

Summary for the evolution laboratory. The explanation task in this unit was different from other units in that students had to pick one of the alternative explanatory ideas. Every student chose the scientifically accepted idea, however, in the defense of their choice some differences were observed. Half of the students used scientific evidence, which came out as an outcome of laboratory activity, in their explanations. On the contrary, a considerable number of students expressed their disbelief in evolution theory explicitly or implicitly.

The Fungi Laboratory Analysis Results

The purpose of the fungi laboratory was to observe the growth of fungi on different food sources and explain how different environmental conditions stimulate or inhibit fungi growth. Students first observed fungi samples from different food sources such as bread, cheese, lemon, etc. In the next step, they were asked to design an experiment that would test the effects of different environmental conditions on fungi growth. Students were given three different pairs of

environmental conditions to experiment: dark/light, cold/warmth, and propionic acid (a food preservative)/non-propionic acid environments. The explanation question was following:

You have everyday knowledge of biology plus you have been studying biology all semester. Based on everything you know about the process of life (such as nutrition, osmosis, cell division, and adaptation), explain why fungi grew better in one of the opposite conditions than the other? Provide explanations for each given pair.

a) warmth/cold b) light/dark and c) propionic acid/non-propionic acid.

The coding of the student work in this unit is provided in Table 4.8

Table 4.8

Emergent codes from the analysis of fungi laboratory explanations

Codes	Examples	Number of Occurrences	Number of students (Out of 13)
Cause	"The cold either killed or slowed down the growth of the fungi."	37	12
Claim	"The fungi grew better in the warmth environment."	23	9
Evidence	"We had more fungi colonies grow in propionic acid than non-propionic acid."	16	6
Conclusion	"...so common sense helps you that non-propionic acid grows better."	14	6
Known fact	"Fungi are known to grow better in warm conditions than cold conditions."	13	7
Elaboration	"In the cold conditions the molecules slowed down which makes it hard for the cell cycle."	7	4
Questioning method	"I think in our experiment we put more mold on the propionic acid side or we didn't put enough of the acid."	5	3

Assertion 7: Providing causes was the most common response in the fungi unit explanations.

Students provided causes for why fungi grew better in one of the conditions. As seen in Table 4.8, almost every student who responded was able provide at least one cause in their

explanations. These causes can be considered as products of inferential thinking, because students had to make inferences after they considered all the available evidence they collected during their laboratory investigation and factual information in order to find a cause that explained the situation. In other words, students identified the causes through processes of inference. For instance in the following explanation, the first statement points to a cause for non-growing fungi in the cold conditions, however, that cause is logical derivation, an inference, from background and prior knowledge. “Cold either killed or slowed the growth of the fungi. The fungi can’t survive in cold conditions. Warm did not kill the fungi; therefore the fungi could survive and grow” (Barbara).

Students often made claims in their explanations. The structure of SWH intervention, to some degree, can explain the appearance of claims in explanations. Before students started thinking about their explanations, their thinking was focused on claims and evidence. Student had to make claims and support their claims with evidence prior to the explanation stage. Therefore, many students might have restated their claims to recall some ideas, and get ready for explanations. In answering the explanation question, it could be more convenient for students to restate the claim as they choose the direction of their explanations. This could be also related to the previous research that reports students often present tautology (unnecessary repetition of ideas or words) in their explanations (Solomon, 1986).

Among the laboratory investigations that included data collection, the fungi unit was different in that students’ findings widely varied. There was not an overall consistency among the results of different groups. In some cases, students’ results were contradictory to the theoretical information provided in the research part of their laboratory sheets. These results were also contradictory to their hypotheses. For instance, students were given the information that fungi grow better in the dark environment better than warmth environment. However, since

students worked with sensitive material such as sterile Petri dish cultures and fungi, during the inoculation process of fungi any mistake students made affected their results. Therefore, some groups found that fungi grew better in the light environment than dark, or better in the acidic environment than non-acidic environment.

Only three students questioned the mistakes they might have made during the experiment, which potentially could have altered their results, in their explanations. In the following example, Macy tries to explain why the fungi grew better in the light environment than the dark environment.

Fungi like moist areas and maybe the light side contained more moisture than the dark side. Fungi also like dark places so I don't understand why it grew better in the light.

Maybe it is because the paper wasn't placed back on so for one day both sides received same amount of light.

In the experiment, students covered half of the Petri dish with a dark colored paper. Macy thought that the cover paper maybe did not make enough of a difference to create two different conditions.

The student responses to fungi growth in the warmth and cold conditions were mostly about the inhibition effect of cold on fungi growth. These students thought that cold conditions either slowed down the fungi growth or killed the fungi. Some students also inferred that warm environment provides a more humid environment, making it a more suitable environment for fungi growth.

The causes that students provided to explain the fungi growth in dark or light conditions varied. When there was an almost equal amount of fungi growth in both conditions, students thought that fungi is a non-photosynthetic organism; therefore light or dark conditions do not

affect the fungi growth. Students who found that fungi grew better in the light environment attributed this to a possible relationship between light environment and moisture or between dark environment and cold. Only one student mentioned about a methodological mistake in the experiment. When there was more fungi growth in the dark environment, which was the case for two students, students justified their explanation with the factual information that says fungi grow better in the dark environment.

The students found different results of fungi growth in acidic/non-acidic environment conditions. When fungi grew better in the non-acidic environment, which was the case for three students, they indicated that common sense explains the situation because propionic acid is used to prevent food spoilage and therefore stops the fungi growth. When fungi grew better in the acidic environment, the students had difficulties in explaining the situation. Some students made unclear inferences and some students could not provide an explanation. In two situation students talked about the mistakes they could have made during the inoculation process. When there was equal fungi growth in the acidic and non-acidic environments, a few students pointed out that since acidic and non-acidic parts were in the same Petri dish acid did not make too much difference.

Students' explanations sometimes showed examples of tautology. In these situations, what was presented by students as an explanation did not add new information to what was already known as data or factual information. For instance, in the following quote Amy tries to explain why fungi grew better in the dark environment in her experiment: "Light and dark were very close, however in the dark, (it was) showing sign of producing spores. Therefore dark grows better than light." In the example above, evidence is presented to prove that fungi grew better in

the dark environment than in the light. However, the student did not explain why signs of spore production were not observed in the light side of the Petri dish.

Another example of tautology is Noah's response: "The reason that the fungi grew better in the warm environment is because fungi can't grow as fast in the cold like it can in the warm." In the above quote, Noah tries to explain the reason why fungi grew better in the warm environment. However, what was provided as a cause does not include any new information, but simply repeats the known idea.

The interview data showed that when students are encouraged to think in certain ways, the horizon of their explanation expands or they talk about the ideas they were not confident enough to write about. For instance, in her written explanation of the fungi growth on acidic and non-acidic environments, Kimberly did not talk about the possible mistakes they might have made during the fungi inoculation process. However, during the interview when she was asked about any other factor that might have been involved in the process that may explain fungi growth in propionic-acid medium, Kimberly brought new ideas that were not in her written explanation.

Deniz (D): For the acids... wouldn't you expect no growth at all in propionic acid condition?

Kimberly (K): It grew basically the same. I mean...

D: That is interesting.

K: We probably messed it up. I didn't put the sample on that one. Barbara and Linda did it.....

D: So, this is propionic acid, and so this is non-propionic acid [referring to the data table in the laboratory sheet]. Can you think about any factors that played role in this growth

that we didn't notice, like besides those three conditions, or in this case with these two conditions? Can you think of any flaws or something we ignored that might be important on results?

K: We did have to open the top, and it probably got...since we were up and those mold spores and people somewhere around and probably get different mold spores of their own. We probably didn't get enough of the samples, or got too much or it just didn't work.

Summary for the fungi unit. In the fungi unit, students' explanations generally included causes, claims, and evidence. Almost all students identified a cause that explains the different rate of fungi growth under different conditions. The students inferred these causes from the known factual knowledge, personal knowledge and the data and observations. Although in many situations students had data that contradicted factual knowledge, the knowledge on the laboratory sheets, only few students questioned the method.

The Leaf Stomata Laboratory Analysis results

The purpose of the leaf stomata laboratory was to determine the location and density of stomata on leaf, to understand the structures and function of guard cells and stomata, and understand how different environmental conditions affect leaf stomata. Briefly, students first observed the stomata and guard cells samples from different plants under microscopes and recorded the number of stomata observed in the lower and upper epidermis of a leaf. They then applied NaCl solution to observe the reaction of guard cells and stomata.

The following questions were asked as explanation questions:

a) Explain why it is an advantage for a plant to have most of its stomata on the underside of a horizontal leaf.

b) Explain how guard cells respond to hot and dry conditions. How might this affect photosynthesis? Why?

The first explanation question required students to process the information they learned from the background section of their laboratory sheet and their laboratory results. In pre-laboratory discussions and in their readings students learned that conservation of water is crucial for plants to survive. Students also had a chance to observe the reaction of guard cells to an extreme physical condition (i.e. salt water environment) by controlling the stomata openings.

After having this laboratory experience and reading relevant background information on the laboratory sheets, the students were asked to explain the functional advantage of horizontal leafs having their stomata on the underside. Student responses to this question can be considered as causal explanations. However, by naming a cause students actually made hypotheses based on the available evidence and information they know about the leaf stomata.

Assertion 8: Misconceptual understandings affected the qualities of students' explanations.

Only five out of 12 students who responded to this question provided a plausible explanation. Remaining students could not provide an answer that addresses the water conservation mechanism.

The plausible explanations are those that are based on the scientifically correct information, represent true understanding of the concepts involved, and utilize the most relevant scientific information to the phenomenon explained. Implausible explanations, on the other hand, represent misconceptual understandings or incorrect or irrelevant scientific information.

The following explanation is a plausible explanation given by Ben. In his explanation, Ben pointed out that to avoid direct exposure to sunlight, stomata are located on the underside of the leaves.

So the sun will not be directly on the guard cells and make the water dry up and cause water loss. Which will allow the guard cells to stay open much longer without worrying about the water being observed out doing photosynthesis.

There were also students whose responses did not address the water use efficiency but other issues. For instance, in the following examples students' explanations were not the expected responses and they can be considered implausible explanations.

Because most of the stuff enters comes from the underside so they need more there to control what comes in and out (Bart).

So that dirt and grit cannot get in there with the rain. The plant might need sunlight but not water. So it can get it sunlight to photosynthesize without water (John).

Less stomata on inside so less loss of food stored in stomach through stomata (Sandy).

Some of the ideas presented in the above explanations are at best intuitive, otherwise wild guesses. All of the three explanations above in one way or another fail to be plausible. These explanations do not relate the structural arrangement of stomata with water use efficiency. Although Bart and John demonstrate some thinking about the problem, their premises are not necessarily correct, and neither are their explanations. Sandy's explanation is also not correct and represents a major misconception.

In the analysis of explanations given to the first question, two different codes were identified: hypotheses and elaboration of ideas. Every student who answered provided a reason (cause) to explain the location stomata on a leaf, however, what they presented as causes were

hypotheses. Students made their hypotheses based on their prior knowledge as well as the knowledge they gained during the laboratory investigation.

The second part of the explanation question required students to make predictions for a certain situation given the available information. Therefore, students' explanations for the second question in this unit were structured around a hypothesis. Most students made a hypothesis about the responses of the guard cells to dry and hot conditions. In the next stages of their explanations, these students provided further information as to why they believe the idea they presented in their hypothesis will take place. In other words, students tried to justify their hypotheses. Students often presented causes and effects to explain the guard cells' response to hot and dry conditions. For instance:

When it is hot and dry the guard cells close up. They do this so that water can't transpire through the stomata. They close, so nothing can enter or exit. When it is closed, the plants can't acquire carbon dioxide, this is an important chemical needed to perform photosynthesis (Elizabeth).

In the example above, the student first made a hypothesis about how guard cells will respond to hot and dry conditions. Then she provided a reason for why guard cells will close, and finally she explained how this behavior would affect photosynthesis.

Most students provided an explanation for the guard cells' response; however, few students could relate this with photosynthesis rate. Only a half of the 12 students who responded to the question mentioned a change in the photosynthesis rate. Most of these responses were unclear about how the photosynthesis rate would be affected. Only one student, Elizabeth, could make the connection between the plants intake of carbon dioxide gas and the photosynthesis rate.

Other students who talked about the decreasing photosynthesis rate could not explain specifically why the photosynthesis rate would decrease. For instance:

They may close in hot conditions but may open some but they stay closed even more in dry conditions because of the lack of water. They don't want to lose the water they have.

Photosynthesis is slower, because guard cells stay closed more (Laura).

In the example above, Laura does not clarify how closed guard cells result in a lower photosynthesis rate. There were also four more students who correctly hypothesized that photosynthesis rate will decrease when stomata are closed, but they did not provided enough information why stomata would close. Findings from this unit support *Assertion 4*, which stated students had difficulties in making causal connections among intricate biological phenomena. To explain the change in photosynthesis rate students had to know about the function of guard cells and stomata and also understand how these functions are affected by different environmental conditions. A summary of the analysis of students' explanations for the second question is provided on Table 4.9.

Table 4.9

Emergent codes from the analysis of leaf stoma laboratory explanations.

Codes	Examples	Number of Occurrences	Number of students (Out of 12)
Hypothesis	"Guard cells close in hot conditions."	17	11
Cause (for hypothesis)	"They do this so water cannot transpire through the stomata."	11	6
Condition	"When it is dry."	12	5
Effect	"The plant can't acquire carbon dioxide."	9	6
Elaboration	"This is an important chemical needed to perform photosynthesis."	3	3

Summary for the leaf stomata laboratory. One explanation task in this unit required students to explain an adaptive structure, which was the difference in the distribution of stomata on the

different side of a leaf surface. Every student who responded to this task was able to hypothesize about the explanation question. However, students' explanations sometimes included misconceptual understandings. Students who understood the structure and function of stomata gave more reasonable explanations. The second explanation question in this unit required students to make some hypotheses about the guard cells responses to extreme environmental conditions using their theoretical knowledge of guard cells. Students also had opportunities to observe the reaction of guard cells to different conditions. Again, students who understood the structure and function of stomata/guard cells provided more sound explanations.

Further Assertions From the Analyses of Science Letters

From the researcher's standpoint, the purpose of science letter writing activities was to collect more data on students' scientific explanations. Science letters provided students with opportunities to demonstrate not only their scientific understanding of the subject matter but also their scientific communication skills.

Answers to the explanation questions in the laboratory sheets demanded more formal scientific language, with little concern for establishing rapport with the readers. The context of the explanation was obvious for the students and the readers (i.e. the teacher and researcher). On the other hand, the science letters were written to a specific person (e.g. an eighth grader, a neighbor, etc.); students used greeting words, introductory passages, and gave advice; and they attempted to influence their readers not necessarily to convince them to believe in a certain way, but to convince them that they have a good understanding of the problem or phenomenon they explained. Therefore, the language of the science letters was different from the laboratory explanations to accommodate the concerns mentioned above.

The explanation questions at the end of each laboratory unit, attempted address the specific outcome of the laboratory investigations. Science letter writing tasks (See Appendix D), on the other hand, provided opportunities for broadening some of the ideas that students faced in the laboratory investigations. For instance, the science letter activity in the osmosis unit required students to apply their knowledge of the osmosis principle to a new situation. Those students who had a true understanding of the osmosis concepts could answer the explanation question asked in the science letter activity.

Forty-three science letters from four units were analyzed. Because of the time constraints, students were not asked to write a science letter in the fungi unit. Also, in the evolution unit, because of the sensitivity of the subject, the classroom teacher did not want to have students write science letter in that unit.

Since students' science letters were guided by a rubric, the patterns in students' science letters were shaped by the rubric. The reason for the use of rubrics was to keep students on the topic while guiding them through the writing process. It also helped students to organize their ideas. For instance, in the osmosis unit science letter rubric students were asked to define osmosis and diffusion. As they made these definitions they recalled some information which helped them to answer the explanation question in the letter. However, students had to conceptualize the definitional information in combination with their laboratory experience to explain the question.

Most students' explanations included an introduction paragraph in which they indicated their purpose for writing the letter and to establish a personal relationship with the reader. An example of establishing a personal relationship follows:

“Dear Anna,

I’m sorry to hear that your child may have sickle cell anemia. I know that you don’t understand how your child can have it when you nor the child’s father has had it.

Therefore I’m writing to hopefully clarify this for you” (Macy).

Students then provided specific information that addressed the explanation questions or writing tasks. This information was typically what was indicated in the rubric, for example the definition of terms, or appropriate use of scientific terminology and explanation of the questions.

Assertion 9: Students have difficulties in applying previously known theories to new situations.

The analysis of the science letters in the osmosis unit indicated that only four out of thirteen students could give a satisfactory explanation of the phenomenon presented in the question, suggesting that students have difficulties applying the concept or principles they learned into new situations. In the writing task students were asked to explain the following: “If a bowl of fresh strawberries is sprinkled with sugar, a few minutes later they will be covered by juice. Explain why this happens.” Prior to this question students were also asked about the definitions of diffusion and osmosis and how osmosis principle works.

Students’ difficulty in explaining the strawberry questions could be interpreted by social constructivist ideas. When students work within groups during laboratory investigations, they bring their prior knowledge and alternative conceptions. During the interactions among group members, students share their ideas and they possibly influence others opinions. For instance, some students can know more about the topic, and these students can be referred as “expert” students. On the other hand, some students can have limited knowledge or they can have alternative conceptions that are different from the scientific view. These students can be referred

as “novice” students. Through interactions and discussions, “novice” students’ learning can be scaffolded so that these students can develop more sound understanding of the topic. In the strawberry example, students did not have group work experience; therefore, some students’ difficulty might have originated from lack of a group experience. Also, the absence of observational data and sensation of the phenomenon as well as SWH prompts might have hindered their thinking. When students have a chance to observe a phenomenon, and are demanded to make claims based on evidence their thinking is more guided than when they write science letters. Therefore, the difficulty some students had in answering the strawberry questions might have been due to the lack of guidance during the writing of letters.

As seen in table 4.10, students’ explanations differed in quality. Among the 13 students who wrote an explanation letter, nine of them attempted to answer the question about the strawberries. Only four students gave a satisfying or somewhat satisfying answer to this question. Satisfactory explanations were those, which correctly applied the osmosis principle to the example. There were also students who tried to apply the osmosis principle to the strawberry example but could not provide a clear explanation at the end.

For instance in table 4.10, the first example represents a successful application of the osmosis principle into a new situation, with the exception of the confusing last statement. The statement that indicates there was a hypotonic reaction confuses the reader, for the term hypotonic is used to refer a solution rather than a reaction. Nonetheless, Elizabeth’s thinking overall represented a good understanding of the osmosis principle.

Table 4.10

Examples of student explanations for the strawberry question

Elizabeth	Laura	Janice	Tracey	Ben
“This happens because the concentration inside the strawberries is greater than the concentration outside of the strawberry. This is a hypotonic reaction.”	“The water retained by the strawberries is attracted to the sugar molecules because they have a lower concentration of water and sugar mix, they form a sticky juice.”	“The reason is because hypotonic, the sugar was absorbed which made a juice like of some sort came out of the strawberries.”	“When the strawberries are sprinkled with sugar, the sugar draws the juice out of the strawberry by the process of hypertonic.”	“This is because while the strawberries are sitting there with sugar on them, the sugar is sort of softening the strawberries and pulling out the juice inside them. This is because the sugar acts like an acidic solution and softens the surface, which then causes the strawberries to sort of leak out their inside.”

There were also student explanations that somehow implied the water density difference between strawberries and sugar molecules, but did not clearly indicate the how the difference caused an effect nor clearly make a connection to the osmosis principle. Janice and Tracey’s examples are in this category. In Tracey’s response, it is understood that because of the sugar water molecules come out of the strawberries, but he does not provide a clear account of how this happens. Although he implies sugar molecules were hypertonic and therefore absorbed the water molecules, the evidence of Tracey’s understanding remains tacit.

The last example in the table represents a misconceptual understanding. Ben thinks that the reason for water to come out of the strawberries is the acidic effect of sugar molecules on strawberries. Perhaps, Ben established a wrong analogy between sugar and vinegar. In the osmosis laboratory acidic vinegar solution had softened the eggshell, therefore Ben probably thought that sugar had similar effect on the strawberries.

Nature of Students' Epistemologies Related To Scientific Explanations

In the context of this research study I used the word epistemology as referring to sources of knowledge and types of reasoning involved in the process of constructing scientific explanations. The research question three, which was about the nature of students' epistemologies, was indirectly answered as the research questions one and two were answered.

The first question was about the meanings that students attached to the scientific explanations. As stated previously, students did not have a clear understanding of scientific explanations. However, students overall thought that data, evidence, observation, hypothesis and experimentation are important components of scientific explanations. Students saw explanations as constructed entities from the data. The items in students' concept maps of scientific explanation also supported this view; students' concept maps reflected the processes that students followed during their science laboratory investigations. Many students viewed explanations as final product of the laboratory investigations. Among all students, only Macy included the word "theory" as a relevant idea to the explanations in her concept map.

The answer to the first research question indicated students held an empiricist view of scientific explanations in which explanations are seen as constructs from the observations and evidence. Thus, the source of knowledge for the students' explanations was their empirical evidence.

The second question was about the characteristics of students' explanations. The revealed characteristics of students' scientific explanations corresponded with the empiricist view of scientific explanations. Students did not use scientific theories or principles when they were needed (for instance, osmosis unit explanations). Students did not use deductive reasoning in their explanations. Students could not provide coherent accounts of theoretical explanations. Further evidence for this assertion came from the analysis of science letters. Only four out of 13 students could apply the previously known osmosis principle to a new situation. Since students did not have any empirical experience for the new situation, they had difficulties constructing their explanations.

Students had difficulties in making causal explanations of intricate biological phenomena, such as sickle cells anemia, or the controlling of photosynthesis rate by the functioning of guard cell and stomata. These characteristics of students explanations indicated that student do not reason at the level of scientific models and theories. However, students can make inferences and predictions from their observations, evidence, prior knowledge, and the factual knowledge provided in the laboratory sheets. Students can also make connections between different events.

During the interviews students were asked about the sources of information they used to make scientific explanations. Students usually listed a combination of sources for scientific explanations. However, three distinct types of priorities were identified as sources of knowledge for students' scientific explanations: Students who think that their data and hands-on experience are the most important knowledge source for their explanations, students who think that textbook and teacher knowledge are the most important sources of knowledge for their explanations, and students who had an eclectic approach to hands-on data textbook information.

The number of students in each of those categories was five, five, and three respectively. Students' written explanations, however, as discussed above suggest that students are more likely to use the data and first-hand knowledge in their explanations along with the brief background information provided in their laboratory sheets.

In the interviews students were asked about the type of classroom activities and knowledge sources from which they learn the most. Every student in the study consistently said that they learn best when they are involved in hands-on activities and experiments. When asked how a scientist learns about new things that have not been known before, all students said by doing experiments and following the scientific method. Overall, triangulated data analyses indicated that students held an empiricist view of scientific explanations and the nature of science.

Genre Characteristics of Students' Explanations

In this study, two different criteria were used to examine the language of students' explanations: lexical density and logico-semantic relationships. Lexical density was defined more in detail the methods section. It refers to average number of content words per clause. Content words include nouns, verbs, adjectives and adverbs. Other elements of clauses do not count towards content words, and they are called no-content words, such as auxiliary verbs, pronouns, or conjunctions. When lexical density is calculated, the proportion of content words to the total number of words in a clause is taken. When we speak of the lexical density of a text, the average number of content words per clause is meant.

The lexical densities of students' explanations were determined for each explanation given for each laboratory unit investigations. Figure 4.3 shows the average lexical density for each of the six laboratory units.

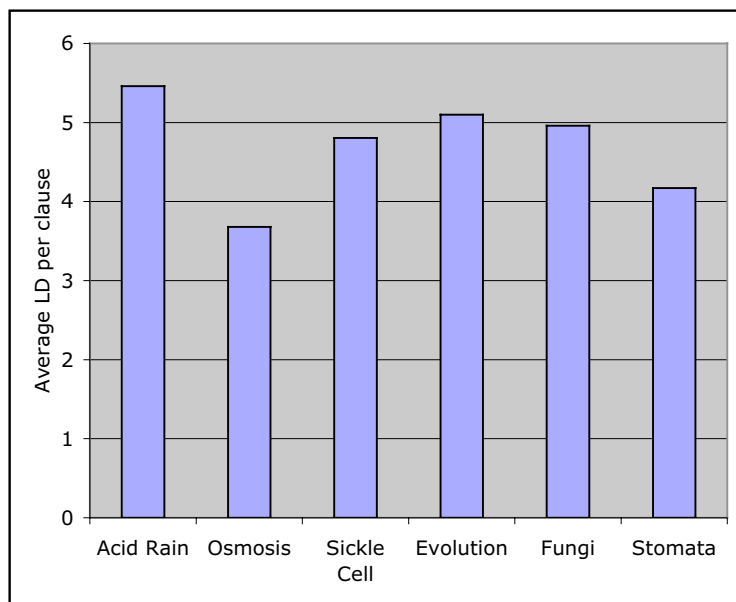


Figure 4.3

Average lexical density per clause values for students' laboratory explanations

As the figure shows, the highest lexical density was in the acid rain laboratory (5.4) explanations, followed by the evolution (5.1) and fungi laboratory (4.9) explanations. The lowest lexical density was in the osmosis unit (3.6) explanations. The overall average value of lexical density per clause for six science laboratory unit explanations was 4.6.

The student explanations in the acid rain unit were very short. These short explanations often included phrases or segments that were directly copied from the reading text, therefore the lexical density of students' explanation were the highest in this unit. For instance in the following explanation that was provided by Ben, there are 10 contextual words. “**Acid rain affects the seed germination process by breaking down the molecules in a living organism.**” This sentence was copied from the extra reading material.

In contrast, in the osmosis unit, students wrote their explanations with their own words. In this unit, the students' explanations focused on the observations, which represented a here-

and-now language; therefore lexical density in that unit was the lowest. In the following example there are total 13 lexical words in four clauses, which averages 3.25 per clause.

When the **egg** was **removed** from **vinegar**||, I **observed** that it was **hypotonic**|| because the **water moved** in. Therefore, there was a **higher water concentration** and a **lower solute concentration** (Macy).

Overall students' use of scientific terms was also a factor in the lexical density values. The more students used scientific terminology, the higher was the lexical density. Every day speech averages two content words per clause. When the language is planned and organized, lexical density values increase. For instance, texts in journals such as *Scientific American* have a lexical density of 10-13 (Halliday & Martin, 1993). The lexical density values of students' explanations in this study suggest that the level of language used by students is more complex than spoken language. However, the language used by students is well below the language used by professional scientists. In a previous study, Keys (1999) found that the lexical density of middle school students' laboratory writings averaged 3.7. A cursory comparison between the results of Keys' study and the current study suggests that high school students' lexical density per clause increases about one from the middle school level. However, since variables that may affect the students' lexical density, such as the type of writing tasks, content, students' background etc., were not considered between the two studies and further evidence is needed to back up this claim.

There were also individual differences among the students. Two students had lexical density slightly over 6, three students had lexical density between 5 and 6, seven students had lexical density between 4 and 5, and four students had lexical density between 3 and 4.

The second criterion that was used to analyze students' explanations was logico-semantic relationships. Logico-semantic relationships help us understand the nature of the relationships between clauses in a text. By analyzing the logico-semantic relationships in a text, we can have some idea about the complexity of that text. When number of logical relationships increase, the complexity of the text also increases.

There are different types of logico-semantic relationships. Four common types of logico-semantic relationships are additive, comparative, temporal and consequential relationships. Additive relations are designated with conjunctions like “and” or “or”. Comparative relations are designated conjunctions like “likewise” or “but” (Veel, 1997, Unsworth, 2001).

Among the logical semantic relationships, temporal and consequential relations are of the most concern to us in examining students' explanations because these two types of logical relationships represent two distinct types of discourses. According to Veel (1997), an increased level of consequential conjunctions, similar to increased lexical density, indicates a shift towards a more abstract discourse. In temporal relations, order of events is emphasized using conjunctions like “while”, “as,” “then” or “after.” Consequential relationships, however, represent a more complex relationship between the events or ideas. Consequential relationships tell us how one event determines the other, or how one event enables the other (Veel, 1997). In other words, consequential relationships show us the causal links between different events or phenomena.

Conjunctions that represent consequential and temporal relationships are shown in Table 4.11. These were the conjunctions that were also used in the analysis of students' explanations.

All of the conjunctions shown in Table 4.11 were searched in students' explanations for each different laboratory investigation unit. Total numbers of temporal and consequential conjunctions were determined for each laboratory investigation explanation.

Table 4.11

Conjunctions that represent temporal and consequential relationships

Type of the Relationship	Example of Conjunctions
Temporal	while, as (simultaneous) then, after (successive)
Consequential	if, unless (condition) because, since, therefore (consequence) by, thereby (manner) although, though, however (concession) so, so that (purpose)

In some units, the students' explanations were shorter in length than others. Therefore, the number of conjunctions for each unit was affected by the length of students' explanations as well as students' choice of using those conjunctions. In order to be able to get a more standard measure, the average number of conjunctions per clause for each laboratory unit investigation was determined. Figure 4.4 shows these values.

As seen in Figure 4.4, students overall used more consequential relationships than temporal relationships in their scientific explanations. As the figure shows, the fungi unit explanations included the most consequential conjunctions per clause, while the osmosis unit explanations had the most temporal conjunctions per clause. In the fungi unit, in average every two clauses had one consequential conjunction. In the lexical density analyses, the osmosis unit explanations had the least content words per clause. Not surprisingly, osmosis unit explanations also had the least number of consequential relationships among all laboratory unit explanations. These findings confirm that in the osmosis unit, the language of students' explanations was more

representative of a here-and-now language than an abstract scientific discourse. The fact that the osmosis unit explanations had the highest number of temporal conjunctions per clause also confirms this idea, since temporal relationships represent here-and-now language. Had students provided their explanations based on the principle of osmosis rather than based on their first-hand observations, the number of consequential conjunctions could have been higher.

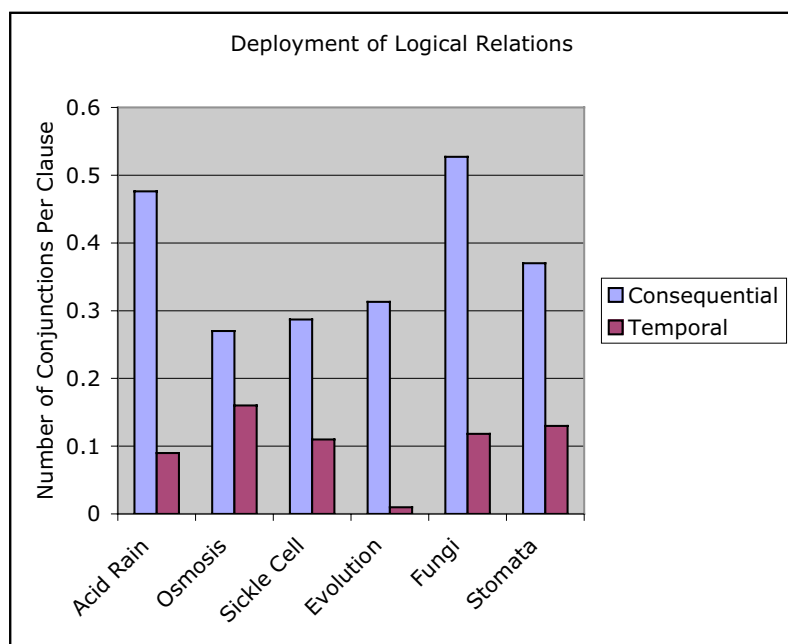


Figure 4.4

Deployment of consequential and temporal relationships in students' laboratory explanations

In the fungi unit explanations, students most often provided causes for why fungi grew better in one of the conditions. There were consequential relationships between the causes students identified and different amounts of fungi growth. This relationship can explain why most consequential conjunctions per clause was observed in the fungi unit.

It was interesting to see that there were almost no temporal relationships in the evolution unit explanations. The explanation questions required students to choose one of the choices that are best supported with the available evidence that was brought by evolution theory. There was almost no temporal relationship evident in students' experience.

Sickle cell anemia laboratory explanations could have had more consequential relationships, because the development of a sickle cell anemia disease involves a series of cause-effect mechanisms. However, as found in the analysis of this unit, the large majority of students failed to provide a comprehensive account of all the cause-effect mechanisms involved in the development of sickle cell anemia disease. This can explain the relatively lower number of consequential relationships in students' explanations of sickle cell anemia disease.

Summary for the genre characteristics of students' explanations. Findings from this section suggest that language that the students use, on average, contains more content words than everyday speech; however it contains far fewer content words from scientific texts. There are individual differences in the lexical density of students' explanations. Students' explanations included more consequential relations than temporal relations, which confirms the genre characteristics of explanations defined in various literature (Halliday & Martin, 1993; Unsworth, 2001; Veal, 1997). Students' greater use of consequential relations over temporal relations can be interpreted to mean students are successful in making connections between related ideas. However, the existence of a consequential relationship does not necessarily indicate that students made the correct connections or provided accurate information. The results of this section also confirmed some of the findings of unit analyses. For instance, previously it has been asserted that student use of theoretical knowledge was limited in the osmosis unit, and the relatively low values of consequential relationships and lexical density support this finding.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

Summary of Findings

The purpose of this study was to examine high school biology students' written explanations provided during science laboratory investigations. It was a qualitative interpretive study that used the Science Writing Heuristic intervention. The following questions guided the study.

- 1) What are students' meanings of scientific explanations?
- 2) What are the characteristics of high school students' scientific explanations?
- 3) What is the nature of students' epistemologies related to scientific explanations? (e.g. source knowledge or evidence drawn upon to provide an explanation)
- 4) To what degree do students' explanations represent the characteristics of explanation genre identified in the literature?

Meaning of Explanations for the Students

Three common themes were identified that represented students' understanding of scientific explanations. The first theme was scientific explanations as "something" that represents the truth, exactness, and reality. The second theme was explanations as a final stage of an investigation. The third theme was explanations as related to first hand-experience and observations. Students often mentioned the importance of data and evidence collected in the investigation in providing an explanation. When asked about the difference between daily life explanations and scientific explanations, half of the students indicated scientific explanations are

based on evidence and more detail, while daily life explanations do not require very much evidence. The other half of the students did not name a significant difference between daily life explanations and scientific explanations.

Students' Epistemologies Related to Scientific Explanations

The analyses of both interviews and students' written explanations indicated that overall, the students in this study held a constructivist-empiricist view of science and scientific explanations. All 13 students who were interviewed said that they learn best when they are involved in hands-on activities. Students emphasized that the more they interact with objects and use their senses (e.g. seeing, touching, smelling), the more enjoyable and meaningful the lessons. On the other hand, it was evident through the analysis of all lab units that students rarely used scientific theories, models, or principles to support scientific explanations. In situations where evidence existed for students' understanding of a particular theory, students used daily life vocabulary more than scientific terminology.

Related to the students' dependence on empirical data and evidence is that students' scientific explanations of a phenomenon reflect their experience with the phenomena, which is limited in time and space. The students do not explain phenomena with more general language, but with here-and-now language. In other words, students do not talk in general terms of theories, but rather talk about what they have experienced. Most students also do not show deductive reasoning in their scientific explanations. For instance, when asked about why water moved from one place to another in the osmosis unit, students' responses typically represented their observations and other evidence related to the investigation. Few students, however, used deductive reasoning in their explanations. It was interesting that none of the students even

mentioned the word “osmosis” in their explanations. This showed that students in this study were not accustomed to speak with reference to the scientific theories.

The findings from study suggested that students’ reasoning falls into the categories of phenomenon-based reasoning and relation-based reasoning in the epistemological reasoning framework that was suggested by Driver et al. (1996). According to Driver et al. (1996), in phenomenological reasoning the scientific explanations are more like descriptions of a phenomenon; there is no distinction between an explanation and a description. However, in the current study, there was evidence that students can make that distinction between explanations and descriptions. As will be discussed in the discursive shifts section later, students’ explanations were more like the form of procedural accounts, often including the observations and descriptions. The osmosis unit lab explanations included examples of phenomenon-based reasoning. In this unit students’ explanations often included observations about the phenomenon, with very few references to the theory.

The next level in Driver et al.’s (1996) framework is relation-based reasoning where the relations between the different features of a phenomenon can be identified. At this level, students also can make connections between variables and talk about alternatives. The sickle cell anemia lab explanations, for instance, represent this type of reasoning. Students realized the causal relationships involved in the development of sickle cell anemia disease, though for most students their thinking was limited to only one pair of connections when a series of connections could have been made. Model based-reasoning, which represents the most complex reasoning level in Drivers et al.’s framework, was not observed in the current study. At this level, the nature of explanation involves theories and models as premises for deductive inferences.

Characteristics of Students' Explanations

One characteristic of students' explanations was that they have difficulties in identifying the causes and events involved in intricate biological processes. The findings in sickle cell anemia and leaf stomata laboratories (particularly findings from the second explanation question) showed that when there are more than two or three causal links in series of events, students have difficulties in explaining the whole process. Students were successful in seeing the initial causes and the ultimate effects; however, they could not map out the entire process of intricate events with the all steps involved. These findings were similar to the finding in the previous research that students are unfamiliar with causal explanations of biological phenomena (Abrams et al., 2001). Considering causality as an important aspect of scientific thinking, students should be given more tasks that involve causal relationships.

Findings of this study also suggested that students' scientific explanations could be affected by their belief systems. In the evolution lab unit, a considerable number of students were very passionate about their personal beliefs, and therefore they were unable to focus on the intended purpose of the explanation questions. Even though the lab aimed to teach students about the idea that species evolve from a common ancestor with an analogy of diverging branches from the same stem, there were still students who questioned why human and gorillas coexist if evolution ever occurred. Because evolution is a very controversial topic, it was easy to see how students' beliefs affected their explanations. The influence of personal beliefs on our explanations has been discussed in the literature (Klaczynski & Narasimham, 1998). What is called ego-protective reasoning affects learners' explanatory decisions; they tend to choose the explanatory model that best matches with their personal beliefs.

Inference making was one of the common patterns observed in students' explanations. Inferential thinking emerged as a way to help students transform their raw data into more conclusive statements and claims. Considering the students' limited use of scientific theories and principles, inference making can be a vehicle by which students reach an abstract level of thinking presented by theories. Students made their inferences from variety sources, including observations, empirical evidence, factual knowledge (e.g. fungi grows better in dark environment), and intuition or common sense thinking (e.g. acid is supposed to be harmful, therefore...).

Although philosophically it is in conflict with an empiricist view of epistemologies (Ladyman, 2002), "inference to the best explanation" (sometimes called abduction), can offer a good model for science students' thinking. According to this model, when learners have several possible hypotheses that can possibly explain the same phenomenon, they chose the hypothesis that best explains the phenomenon, considering all the available evidence (Ladyman, 2002; Lipton, 1991). Inference to the best explanation can be seen as a discovery process. The following quote shows the differences among deduction, induction, and abduction: "abduction is the process of forming of a hypothesis...Deduction proves that something *must be*; induction shows that something *actually is* operative, abduction merely suggest that something *may be*" (Peirce as cited in Williamson, 2003, p.353). To exemplify abduction, in the fungi unit students tested the effects of different pairs of environmental conditions on fungi growth. When asked why fungi grew better in the warm environments than the cold ones, they had to generate a hypothesis that could best explain the situation. Even though they knew that fungi grew better in warm environment from background information provided in the lab sheets, it was still a question to answer how warm environments provide better conditions than cold environments for

fungi reproduction. To answer this question, students had to make inferences in the forms of hypotheses.

The findings in the fungi unit lab showed that students rarely question the methods of an experiment when the observed results did not match with the expected results. Questioning method and process of a scientific investigation is an important skill that requires critical thinking; this type of reasoning should be more emphasized in science classrooms.

Although students were encouraged to read the authoritative sources (e.g. textbook, extra reading material attached to lab sheets) to help with their explanations, the majority of the students were reluctant to do so. The analysis of the acid rain and genetics units shows that students were generally unwilling to read the extra material to construct their explanations. Few students in the study read the extra material when it was provided, and gave explanations in the manner suggested on those texts.

The analysis of science letters showed that some students have difficulties in applying a learned principle or theory into a novel case. For instance, the science letter activity given at the end of the osmosis lab showed that only four out of 13 students could successfully explain the previously known phenomenon in a novel case. This data from the science letters confirmed the assertion related to students dependence on the empirical data and their limited use of theoretical knowledge. If students were acquainted with explaining through scientific theories they could have possibly made better explanation of the strawberry question using the rules of deduction.

Genre Characteristics of Students' Scientific Explanations

The lexical density values of students' explanations indicate that students' writing overall represents a language richer than everyday speech. However student lexical density values were well below the values found in scientific texts. Students were in general successful in employing

logico-semantic relationships. Student made more consequential relations than temporal relations. The genre characteristics of students' explanations varied across individual students as well as individual lab units. Some of the students' genre characteristics supported assertions made about the limited use of scientific theories. For instance, in the sickle cell anemia lab students were expected to make causal explanations, but they were not completely successful at that task. Their lack of ability to make causal explanations in this unit was also evident in their use of consequential relationships. Along with the osmosis unit, the sickle cell anemia lab analyses yielded the lowest number of consequential relationship per clause in students' explanations.

Variables in Students' Explanations

There are several factors that are involved in the process of constructing scientific explanations. Studies in the written communication field (Rowan, 1990) suggested that explaining difficult ideas is related to measures of topic knowledge, social cognition, and discourse knowledge. The content knowledge of and a conceptual understanding of the subject matter, which the phenomenon explained, are obviously important. Without some sort of understanding of the phenomenon it is almost impossible to give a sound explanation. Regardless of one's level of content knowledge, the skills and the ability to construct an explanation are also important. Some of these skills and abilities are developed through increased age. The previous research on developmental psychology and science education suggested that cognitive capacity to identify causes, evidence, evaluate and interpret results highly correlates to age (Krupa et al., 1985; Metz 1991).

The other part of skills and abilities has to do with language. As discussed earlier, scientific explanations represent a unique genre. Students who are more familiar with the

understanding of this genre will construct their explanations much easier than those who are not familiar. Students' individual written communication skills are also important.

In the context of current study there were several variables that have not been investigated, but could have affected the quality of students' explanations. These are, students' prior knowledge, students' individual writing performances, students' level of interests, and students' cognitive capacity and abilities.

Situated/Pragmatic Nature of Students' Explanations

There is lack of standard criteria to decide what counts as a good explanation. We can distinguish some ways of explaining from others, however to decide what counts as a good or appropriate explanation could be an inextricably difficult task. Many times what makes an explanation good is not decided by crystal clear rules, but whether the explainer satisfies the expectations of the explainee.

When explanations are perceived as a response to an explanation question posed, then the construction of an explanation is in the form of an interplay between the person who requested the explanation (teacher) and the person who gives the explanation (student). Therefore, the explanation is contextualized within the common understanding and shared meaning of concepts and ideas that reside in both parties. What counts as a legitimate explanation in one situation, therefore, may not count as legitimate in another situation. This view recalls what is known as a pragmatic view (van Fraassen, 1997) of explanation in the literature of the philosophy of science. Simply put, in this view, explanations have pragmatic value for the person who explains it. This pragmatic approach can have a value for science education, because students often come to classroom with alternative views and knowledge that affect their scientific understanding and conceptualization. Therefore, accepting a pragmatic view of explanation coincides with

constructivist ideas in science education. When pragmatism is accepted, it creates room for creativity for students' explanations; and perhaps pragmatism legitimizes students' alternative views as long as they are logically sound and relevant to the point.

In the context of the current study, students gave their explanations to the specific questions posed. It was not that students decided what to explain after they were exposed to some natural phenomena. Nonetheless, if students had chosen what to explain, they would have still had a question of their own in order to start explaining something. Therefore, it is important to realize that explanations are given to specific questions.

Gilbert et al. (1998) argued that scientific explanations are given to specific questions posed. This view of explanation, explanation as a response to a given question, fits well into the context of this study, for students' explanations were requested as responses to the specific questions at the end of each laboratory investigation.

The results of this study showed that the character of students' explanations varies as the type of science lab investigations undertaken changes. For instance, the explanations given in the leaf stomata lab were in the form of predictions or hypothesis, while osmosis lab explanations concerned what already happened. Therefore in the osmosis unit students were expected to use the osmosis principle to explain their data. In the sickle cell anemia lab explanations were expected to address the causal connection among a series of events. In the evolution unit, student explanations demanded a selection between alternative theories; therefore it was more argumentative in nature. Since there is a variety in the types of explanations, teachers should be aware of what range of explanatory tasks are covered in their practice.

Managing the Shift Between Discourses

Veel (1997) brought the idea of discursive shifts in science classrooms. One important discursive shift is between the procedural knowledge and explanations. While procedural accounts provide information about what happened, or what was observed, they do not necessarily represent an explanation, which provides a more generalized account. Scientific explanations typically refer to generalizable events, because the phenomenon explained can recur or be observed when the same or similar conditions take place. Therefore it is important for science learners to be able to articulate their experience and knowledge with general statements moving beyond the procedural accounts.

Veel (1997) indicates that as the students move forward in secondary school, they are expected to build meanings through more fact- and theory-oriented knowledge (knowing by reading), instead of building meaning through procedural knowledge (knowing by doing). The reason for this shift is that the scientific community and science education privileges certain types of discourses and the meaning created through those discourses over others. Language plays an important role in privileging discourses that are based on fact and theory, because procedural accounts tend to represent more of a daily language. In the current study, students had the most trouble in explaining the intricate causal events that are not readily observable, such as the mechanism involved in the development of sickle cell anemia. Part of the difficulty students had in making causal explanations was that these type of explanations required more theoretical language to explain. This was also true for the acid rain unit explanation and for the second question of the leaf stomata lab, which was about how the guard cells and stomata's reaction to dry conditions affect the photosynthesis rate. The results of the current study suggested that

students in the study were not able to make the discursive shifts successfully from the procedural discourse toward theory and principle-oriented explanatory discourse.

Summary. This research study showed that students could make explanatory hypotheses, inferences, cite evidence, recognize the causal nature of phenomena, and identify the consequential relations. However, the students had problems in managing discursive shifts between procedural accounts and explanatory accounts, giving explanations based on a theory or a principle, making generalizations, and using deductive reasoning. The students also had difficulties in reading, understanding and presenting explanations from the external sources.

Implications for Teaching

Providing an explanation entails use of some critical thinking skills such as ability to generalize, making causal claims, seeking reasons, considering alternatives, inferring and concluding. It is an important component of scientific inquiry. To quote Trout (2002) “few products of intellectual life are more exhilarating, more pleasing to give and receive, than a good explanation” (p.212).

Contemporary views of science education accept scientific explanations as one of the essential features of inquiry (NRC, 2002). According to the NRC, learners should be able to formulate, evaluate, and communicate scientific explanations. Given the importance of scientific explanations, implementation of science learning and teaching standards regarding the explanations are very important to achieve scientific literacy goals.

Explanation tasks in science classrooms can provide effective strategies for teachers to assess students understanding and identify the alternative conceptions or misconceptions of students. In this study, it was evident in many cases that students’ explanations did not reflect the scientific view of a concept or idea. This was especially true when the explanation task required

knowledge that went beyond the empirical data that students collected. School science curricula should accommodate students by teaching both the empirical aspect and the theoretical aspect of scientific thinking.

Special emphasis should be given to explanations tasks that require processing of both empirical evidence and theoretical information. That will ease the transition process where students have to move from procedural accounts to the more theory-based accounts. Students should be introduced to different types of scientific discourses. Reading skills should be emphasized in order to increase the students' ability to understand abstract and theory-based texts and also their ability to articulate theories in different contexts.

Furthermore, science students at higher grades of secondary education eventually should be able to explain the natural phenomena with reasoning that involves deductive thinking. Once students have learned a certain theory or law they should be able to apply that knowledge in different situations. This could be named as the ability to articulate a theory (Ohlsson, 2002). As Ohlsson indicated, theory articulation is an important aspect of scientific literacy and without understanding the ways scientific theories operate, science literacy aims will not be achieved.

Special attention also should be given to explanations of phenomena that involve cause-effect relationships. Most causal accounts involve events that cannot be readily observable (e.g. physiological and molecular biological phenomena); therefore they automatically require a language that refers the entities that go beyond the language of procedures and daily events. Particularly in biology, functional explanations (adaptive) are very common. Most biological phenomena can be related to an adaptive feature. Students should be encouraged to think in terms of the form and function of biological structures. For instance, the explanation in the leaf stoma lab required an understanding of the form and function of guard cells and stomata.

Students who understood the function of those structures made better explanatory predictions as to the behavior of the organism when the environmental conditions changed.

The results of this study suggested that students generally do not refer to their textbooks or the other reading material when they are advised to seek help from those authoritative sources. As Unsworth's (2001) analysis of science textbooks revealed, there are structural units in the science textbook explanations that appears in patterns, such as phenomenon identification, analogical accounts, or conditions etc. Even though purposes, scopes and levels of explanation given in science textbooks may be quite different from students' scientific explanations; science texts can help by scaffolding students' understanding of the structures of scientific explanations. For instance, as Unsworth (2001) suggested, students can be provided with scientific explanations taken from various textbooks about the same topic and can be asked to negotiate the meanings in different accounts of texts.

Suggestions for Future Research

Although the role of argumentation in schools has been discussed by many scholars (Driver, Newton, & Osborne, 2000; Newton & Osborne, 1999), scientific explanations have not been the same amount of interest yet. As rhetoricians have indicated, the study of explanations as a genre is relatively much younger than studies of argumentation (Connors, 1985).

Linguists define scientific explanation as a particular genre (Halliday & Martin, 1993; Veal 1997); however the question of whether the structural characteristics of genre can be taught explicitly is yet to be answered in science education, (Chambliss et al., 2003). Therefore, further research should focus on the effective ways of teaching the explanatory genre, as well as developing assessment strategies of scientific explanations. Because there are many views of

explanations found in the philosophy of science (Ladyman, 2002; Mayes, 2001), science educators should carefully assess the value of these models for science teaching and learning.

The design of this study did not allow the researcher to observe the changes in the quality of students' explanations over the course of the semester. However, the feeling that I had during the course of my research was that students adopted the style of the intervention that was used. As the weeks passed, students asked fewer questions about how they should write their explanations. Perhaps constructing explanations is an intellectual acquaintance that students develop overtime. Further research can investigate whether explicit instruction of explanatory schemata supported with writing tasks can improve students' ability to provide scientific explanations.

There is evidence in the literature that collaborative tasks can improve the quality of students' scientific explanations (Meyer & Woodruff, 1997). Previous research also showed that students' scientific reasoning improves with the collaborative writing tasks (Keys, 1994, 1995). However, there is not much research that specifically investigates the effects of the collaborative writings on students' written explanations. It could be interesting to investigate how peer interaction with collaboration affects the quality of students' scientific explanations.

Another focus of interest could be the effects of peer critique in providing scientific explanations. When students were asked to critique their peers' explanations, the process of critiquing can help students to realize the structures of explanations in term of the logic and language used. While critiquing, the student has to develop a set of criteria in his/her mind in order to evaluate peers' explanations. This could help the student to understand the genre of explanations and different ways of explaining. By understanding the structure and language of explanations, students, presumably, could improve their ability to explain.

Further research can also investigate whether the quality of students explanations improve when they were explicitly taught about the genres of explanations in comparison to students who were not taught with genre forms of explanations.

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APPENDIX A

The Interview Guide

1- Think about what makes a good scientific explanation and other characteristics of scientific explanation, and please draw a concept map.

2-Are your scientific explanations different from your daily life explanations? If so how?

3-What kind of knowledge (e.g. textbook, lab, or personal) do you draw upon to make a scientific explanation?

4-What is a claim, evidence, and explanation? And how do they differ?

5-What kind of knowledge (data, observations, theory) you need to have in order to provide scientific explanations?

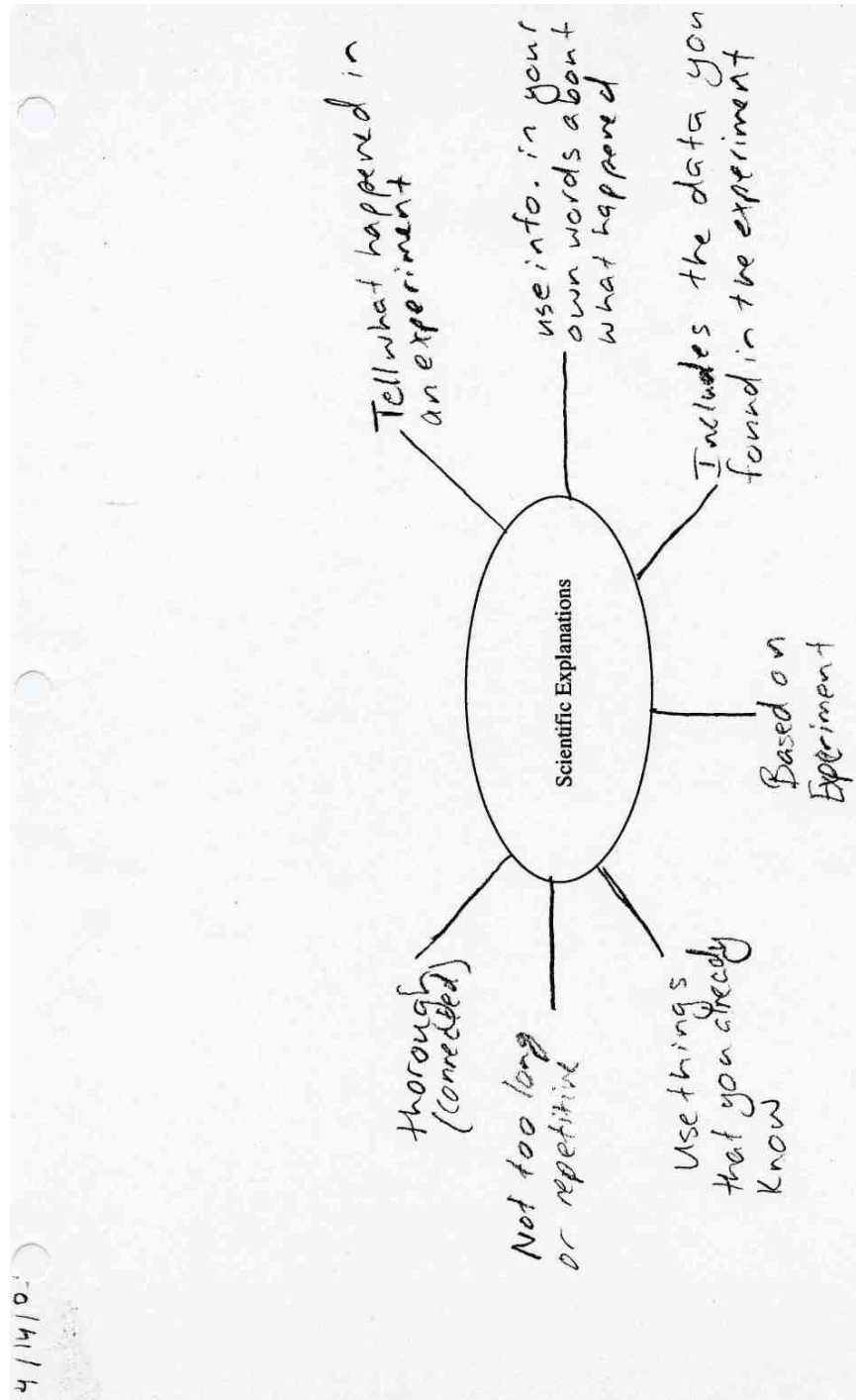
6-I want to talk about your _____unit explanation. Can you tell me more about what happened in that investigation? Why did you think that_____?

7-How do you think scientists learn new things that have not been known before?

8-How similar do you think is what scientists do and what science students do in the lab? Do they follow the same procedures or are there differences?

9-Would you say that science is more like facts to be discovered or ideas put together in new ways?

APPENDIX B
Sample Concept Map About Scientific Explanation (Bart).



APPENDIX C

Students' Views of Science Explanations from the Interviews

Student	View of Scientific Explanation
Allison	"You are just looking data from the experiment and playing out and showing the person this is how it happened"
Amy	"Explanations are just telling what actually happened. It is like facts"
Bart	"That is explaining why something happened. The explanation is like in your own words telling how happened."
Ben	"It is actually explaining what happened instead of... you actually find out the real answer"
Barbara	"Explanation is telling exactly why it happened, how it happened, and exactly what happened"
John	"...explanation is so, it is telling you, if your claims is right, because you use all the data from the experiment, saying what is happening, how is happening.... So, explanation is pretty, really close to truth so to speak"
Kimberly	"An explanation is either explanation of your claim or explanation of outcome, and the outcome is what happened after you do all the experiment"
Laura	"Explanations are what you use to explain the data, you...the evidence you accumulated"
Macy	"In explanation you give evidence. I don't know"
Noah	"Explanation is what did happen, like..., I don't know"
Nikki	"Why it happens after the end of the experiment. You did it and your explanation is why it happened"
Sandy	"Explanation is what you think happened...You need the data, the evidence, the claim, you need what you had in the experiment to explain"
Tracey	"That is the one it shows, what happened in the experiment. It is pretty much like the whole thing, explanation of what happened"

APPENDIX D
Science Laboratory Investigations Lab Sheets

The Effects of Acid Rain

Name _____
Date _____ Ntbk# _____

Purpose: Students will measure the pH of a water solution, observe seed condition and germination. Interpret data showing differences in seed germination under varying pH conditions.

Problem: In what way does acid rain affect the germination of plant seeds?

Research: Cars and trucks spew pollutants into the air through their exhaust pipes. Industries release pollutants through their smokestacks. These emissions include oxides of sulfur and nitrogen. When the oxides combine with the water vapor in the air, sulfuric and nitric acid are produced. These acids precipitate out of the air when it rains, forming acid rain. Pure water has a pH of 7.0, it is neither acidic or basic. Normal rainwater has a pH of 6.2-it picks up some acidity from the air. In areas hardest hit by acid rain, such as the northeastern U.S., rainwater has been tested with a pH as low as 2.8, which is equivalent to the pH of vinegar. Acid rain has devastated entire forests and rendered entire lakes lifeless in the areas most affected by it. Scientists have documented the effects of acid rain on nature and growing trees and on the fish, amphibians, and other organisms in acidified lakes. However, acid rains' effect on the germination seeds is not completely understood. In this lab you will study the effect of acidified water on the germination of seedlings.

Getting Ready for Hypothesis: Pretend you are a seed. Write a short paragraph about what happens to you when you are put in a Petri dish with vinegar. Describe what is happening to your seed coat (skin) and tissues.

Hypothesis: Write a hypothesis about how will varying acid solutions affect seed germination.

Experiment/Procedures:

1. Each lab group (of four people) should obtain five Petri dishes, a marking pen, tape, fifty seeds, five paper towels, and 25 ml of each of the four strengths of vinegar solutions. The vinegar solutions have been made up by the teacher and are labeled A, B, C, and D.
2. Label each Petri dish with a marking pen on tape with your name and the treatment (Solution A, B, C, D, or water).
3. Place a folded paper towel in each Petri dish, and then pour 25 ml of each of the four vinegar solutions onto the paper towel. In the fifth Petri dish, pour 25 ml of water.
4. Place ten seeds inside each folded paper towel.
5. Place the lid on each dish and put in a warm place shown by the teacher.
6. In the next class, retrieve and observe your seeds. Record your data about germination in the table below. Each person fills in the chart according to group data.

Data/Observations:

	Solution A	Solution B	Solution C	Solution D	Control Solution
Number of hard seeds					
Number of soft seeds					
Number of seeds coat broken					
Number of seeds germinated					

Conclusions/ Analysis: Record your answers to the questions below after discussing with your group. Pick one group member to tell your answers to the whole class.

1. What did you observe? Compare the changes in seeds in Solutions A, B, C, D and control using words and/or numbers.

2. (a) What can you claim about which solution (A, B, C, D) is the strongest acid?

(b) Make a claim ranking the strengths of the acid solutions from weak to strong.

(c) Make a claim about the effects of acid rain on seed germination.

3. What is your evidence for your claims? How do you know that your claims about the effects of acid rain are correct? (Hint, use number of seeds).

4. Explain specifically how acid rain interferes with the seed germination process. You may use any of the following resources: everyday knowledge, notes from science class, research information at the beginning of this lab, and the attached information sheet on acid precipitation and the environment.

Letter Activity: Write a letter to an eighth grader (one to two pages) that states (a) what are the effects of acid rain on seed germination and (b) gives a possible explanation for how acid rain affects seed life processes. Give examples and descriptions to make your letter detailed. Your letter will be graded on the following criteria:

Clarity of writing

Supporting your statements with evidence

Includes both description of effects and possible explanation for effects

Level of detail and description

2.16 Acid precipitation threatens the environment

Imagine arriving for a long-awaited vacation at a mountain lake only to discover that, since your last visit a few years ago, all fish and other forms of life in the lake have perished because of increased acidity of the water. Over the past two decades, thousands of lakes in North America, Europe, and Asia have suffered that fate, primarily as a result of **acid precipitation**, usually defined as rain or snow with a pH below 5.6. About 4% of the lakes in the U.S. are now dangerously acidic, with the number close to 10% in the eastern part of the country.

Effects of acid precipitation are also felt on land. The photograph below shows dead spruce and fir trees on Mount Mitchell in North Carolina, where acid precipitation and acid fog have greatly reduced the numbers of these high mountain trees. In cities, acid in the air eats away the surfaces of buildings and contributes to smog.

Acid precipitation results mainly from the presence in the air of sulfur oxides and nitrogen oxides, air-polluting compounds composed of oxygen combined with sulfur or nitrogen. These oxides react with water vapor in the air to form sulfuric and nitric acids, which fall to the earth in rain or snow. Rain with a pH between 2 and 3—more acidic than vinegar—has been recorded in the eastern U.S. Acid fog of pH 1.7, approaching that of the digestive juices in the human stomach, has been recorded downwind from Los Angeles.

Sulfur and nitrogen oxides arise mostly from the burning of fossil fuels (coal, oil, and gas) in factories and automobiles. Electrical power plants that burn coal produce more of these pollutants than any other single source. Ironically, the tall smokestacks built to reduce local pollution by dispersing factory exhaust help spread airborne acids. Winds carry the pollutants away, and acid rain may fall thousands of miles away from industrial centers.

The effect of acid in lakes and streams is most pronounced in the spring, as snow begins to melt. The surface snow melts first, drains down, and sends

acidic conditions. Strong acidity can break down the molecules of living organisms. And even if the molecules remain intact, they may not be able to carry out the essential chemical processes of life at very low pH.

While acid precipitation can clearly damage lakes and streams, its effects on forests and other land life are controversial. The damage to the forest on Mount Mitchell, on one hand, almost certainly results from acid fog and precipitation. The acid apparently causes changes in the soil that lead to mineral imbalances, lowered tolerance to cold, and general weakness in the trees. On the other hand, careful studies over the past decade seem to show that the vast majority of North American forests are not suffering substantially from acid precipitation.

Many questions remain. We do not know for sure what the long-term effects of acid precipitation may be on plants and soils. Nor do we know much about the effects of airborne acids on terrestrial animals, including humans. Perhaps most importantly, we do not know how much we must reduce fossil-fuel emissions in order to prevent more damage.

As with most environmental issues, there are no easy solutions to the acid precipitation problem. There is some hopeful news, however. Between 1970 and 1985, emissions from such sources as automobiles and fossil-fuel-burning power plants in the U.S. dropped 30% for sulfur oxides and about 10% for nitrogen oxides. Laws that require reductions in emissions can go a long way toward alleviating the problem. But just as important is energy conservation. We all need to realize that unless we decrease our consumption of electricity and our dependence on gasoline-powered automobiles, we will continue to contribute to acid precipitation and other threats to the environment.

Spruce and fir trees killed by acid precipitation

Diffusion and Osmosis Lab

Name _____

Date _____ Ntbk # _____

Purpose: Students will observe a) osmosis across the membrane of an egg, and b) measure the amount of water that moves across the egg membrane.

Problem: What will happen to a raw egg when it is put into the following solutions and left in the solutions for a night?

- a) vinegar
- b) syrup
- c) water

Research: Cells have an outer covering called the cell membrane. The cell membrane controls what moves into and out of cells. Food and oxygen move into cell through the cell membrane. They move by diffusion. The movement of a substance from where it is in large amounts to where it is in small amounts is called diffusion.

Osmosis is a special kind of diffusion. Water will move across a membrane from where it is in large amounts to where it is in small amounts. The diffusion of water is called osmosis.

Getting ready for Hypothesis: You are watching a movie at the theater or your favorite sports team's game at the stadium, and you are eating a lot of salty peanuts and potato chips. Unfortunately, you run out of cash to buy a drink. What will happen to you after you eat all the peanuts and chips? How would your body feel and why?

Hypothesis: Write a hypothesis about what you believe will happen to the egg, when it is put in vinegar, syrup and water, and describe how will this happen.

Experiment/Procedures:

Day 1:

1. Each lab group obtains three jars, a marking pen, tape, an egg, graduate cylinders.
2. Label the jars with a marking pen on a tape. Assign each jar to vinegar, syrup, and water.
3. Use the graduated cylinder to measure 200mL of vinegar. Put the vinegar in the vinegar jar. Place the raw egg into the vinegar jar. The vinegar should cover the egg. Cover the jar with the lid. Leave it undisturbed for a day.

Day 2:

4. Observe your results, and write them to the observations section.
5. Put 200 mL of syrup in the syrup jar. Remove the egg from the vinegar and carefully rinse it with water. Place the egg in the syrup jar. It should remain in the syrup jar for one day.
6. Measure the amount of vinegar remaining in the vinegar jar, and write it down to your data table.

Day 3:

7. Measure 200 mL of water and add it to the water jar.
8. Carefully remove the egg from the syrup jar. Make observations and record them. Place the egg in the water jar.
9. Measure the amount of syrup that remains in the syrup jar. Write the amount in the table.

Day 4:

10. Remove the egg from the water. Measure the amount of water that is left in the water jar. Write the amount in the table. Also record your observations of the egg.

Data/ Observations:

Jar	Amount present when the egg was	
	put in	removed
Vinegar		
Syrup		
Water		

Conclusion/Analysis: Record your answers to the questions below after discussing with your group. Pick one member to tell your answers to whole class.

1. What did you observe (use your data and descriptions)
 - a) when you removed the egg from vinegar?

 - b) when you removed the egg from syrup?

 - c) when you removed the egg from water?

2. What claims can you make about the movement of water when
 - a) the egg is in vinegar?

 - b) the egg is in syrup?

 - c) the egg is in water?

3. What is your evidence for your claims? How do you know that your claims about the movement of water are correct?

4. Explain specifically, why the water moved in and out of the egg, when the egg was put in different solutions, such as vinegar, syrup or water? Why in some cases did egg take in water and in other cases did it loss water?

Letter activity:

You are applying for a summer science camp on the beach. But before you can get accepted for the camp, you need to write a letter to the director of the science camp. In your letter (1-2 pages), you should explain:

- a) What is diffusion and osmosis?
- b) How does osmosis principle work?

Since there are many applications are expected this year, approval decisions will be tough. Therefore, the director of the summer camp, Mr. Albert Osmo, also wants applicants to answer the following question:

c) If a bowl of fresh strawberries is sprinkled with sugar, a few minutes later they will be covered by juice. Explain why this happens?

Sickle Cell Anemia Lab

Name _____
Date _____ Ntbk # _____

Problem: Students will identify the genotypes of the members of a family using the DNA gel electrophoresis technique.

Research:

Genetics of Sickle Cell Anemia

Sickle cell anemia was the first genetic disease to be characterized at the molecular level. The mutation responsible for sickle cell anemia is small-just ONE nucleotide of DNA out of the three billion in each human cell. Yet it is enough to change the chemical properties of hemoglobin, the iron and protein complex that carries oxygen within red blood cells (RBC). The hemoglobin molecule has 4 parts and one of these is called beta globin. It is a point mutation in the gene that codes for beta globin that causes sickle cell anemia.

As a result of this mutation, valine is inserted into the beta globin chain instead of glutamic acid. The mutation causes the RBCs to become stiff and sometimes sickle-shaped when they release their load of oxygen. The sickle cell mutation produces a "sticky" patch on the surface of the beta chains and they tend to stick to each other forming long fibers that make up the sickle cell shape. The sickled cells tend to get stuck in narrow blood vessels, blocking the flow of blood. As a result, those with the disease suffer painful "crises" in their joints and bones. They may also suffer strokes, blindness, or damage to the lungs, kidneys, or heart. They must often be hospitalized for blood transfusions and are at risk for a life-threatening complication called acute chest syndrome. Although many sufferers of sickle cell disease die before the age of 20, modern medical treatments can sometimes prolong these individuals' lives into their 40s and 50s.

There are two beta globin alleles important for the inheritance of sickle cell anemia: A and S. Individuals with two normal A alleles (AA) have normal hemoglobin, and therefore normal RBCs. Those with two mutant S alleles (SS) develop sickle cell anemia. Those who are heterozygous for the sickle cell allele (AS) produce both normal and abnormal hemoglobin. Heterozygous individuals are usually healthy, but they may suffer some symptoms of sickle cell anemia under conditions of low blood oxygen, such as high elevation. Heterozygous (AS) individuals are said to be "carriers" of the sickle cell trait. Because both forms of hemoglobin are made in heterozygotes, the A and S alleles are codominant.

About 2.5 million African-Americans (1 in 12) are carriers (AS) of the sickle cell trait. People who are carriers may not even be aware that they are carrying the S allele!

Sickle Cell at the Molecular Level

In sickle cell anemia, there is a mutation in the gene that encodes the b chain of hemoglobin. Within this gene (located on Chromosome 11), ONE BASE in the DNA is replaced with another base, and this mutation causes the normal amino acid #6 to be replaced by another amino acid.

1. Making a Normal Beta Chain of Hemoglobin

The sequence below is the first part of the DNA sequence for the b chain of normal hemoglobin. Fill in the complementary DNA strand using the base-pairing rules for making DNA (A pairs with T, C pairs with G).

DNA: GTG CAC CTG ACT CCT GAG GAG

DNA:

Now make the messenger RNA from the new, complementary strand of DNA that you just wrote down. Use the RNA base-pairing rules (same as DNA but use U instead of T).

mRNA:

Now, using the Genetic Code chart in your textbook, translate this mRNA into a sequence of amino acids.

Amino Acids:

2. Making Sickle Cell Hemoglobin

In sickle cell anemia, there is a mutation at the seventeenth nucleotide of DNA in this gene; the nucleotide is changed from A to T. Fill in the complementary DNA strand, mRNA, and amino acid sequence in the hemoglobin protein.

DNA: GTG CAC CTG ACT CCT GTG GAG

DNA:

mRNA:

Amino Acids:

Question: The question you need to answer in this experiment is that what are the genotypes and phenotypes of the members of family you work with?

Experiment/Procedures:

Precautions: Wear a pair of gloves before you start your experiment. Once you turn on the power supply DO NOT OPEN the lid of electrophoresis until you turn off power supply.

1. Receive the seven "DNA" samples from your teacher. Some groups will have Family 1 and some groups will have Family #2.

Mother	M
Father	F
Teenager	T
Fetus	O
Known Normal	N
Known Carrier	C
Known Sickle Cell	
Patient	S

2. Slide the gel into the box, wells facing up and closest to the black electrode.

3. Using a P-20 micropipette set to 8 ml, load each well in the gel with the samples. Take turns loading with others in your group, making sure to use a new tip each time. Make sure that you record correct order of the samples in your data table.

4. If necessary, add more 1X TAE Buffer to the gel box so that the gel is adequately covered. (The buffer should cover the gel by about 1-2 mm.). Close the lid of the box. Connect the electrodes to the gel box and to the power supply (red to red, black to black).

5. Turn on the power supply and set it at about 120V. Run the gel for at least 10 minutes.

6. Turn off the power supply, unplug the electrodes, and open the gel box. Lift the gel and deck and slide the gel back into the dish, pouring off extra buffer. For better viewing, place the dish on white paper. Color the pattern observed into your results drawing.

7. Throw away the gel and pour back buffer!! Put all equipment back into the supply box.

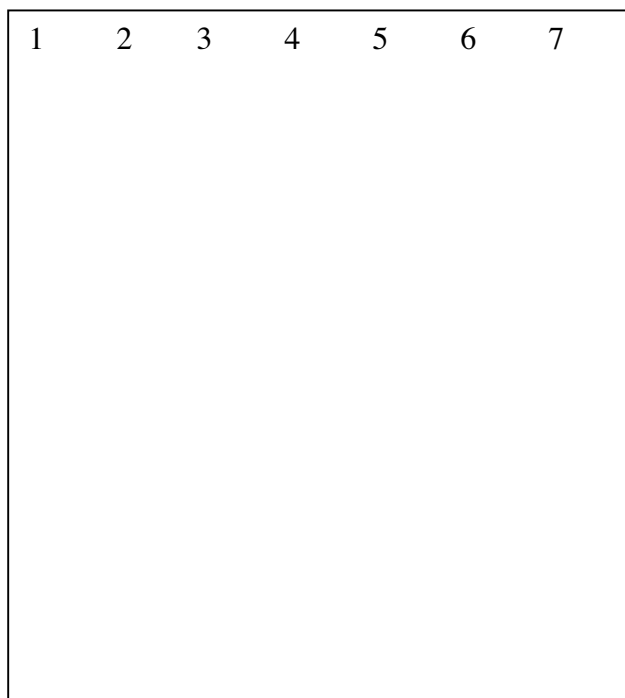
8. Note how the gels for the known genotypes turned out. This will be important to finding out the other genotypes.

Data/Observations:

Draw a gel as shown below and indicate in your lab notebook which sample you put in which lane. Label these results. Draw the + and - ends of your gel so you remember the orientation.

(-)

(+)



Results Diagram

Key:

1:

2:

3:

4:

5:

6:

7:

Conclusion/Analysis:

1. a) What did you observe when the samples run after 5 minutes?

- b) What did you observe when the samples run after 10 minutes?

2. Based on your observations, what claims can you make about the genotypes and phenotypes of the samples? Use symbol “A” for a normal allele, and use “S” for a sickle allele.

Family # : 1 or 2 (circle your family #)

	<u>Genotype</u>	<u>Phenotype</u>
Mother:		
Father:		
Teenager:		
Fetus:		

3. Provide evidence that how you determined the genotypes of your samples? Provide evidence for each individual.

Mother:	
Father:	
Teenager:	
Fetus:	

4. Answer the following questions:

a) Explain the cause-effect mechanism by which a single base mutation on a DNA strand can cause sickle cell anemia disease?

b) Explain how sickle cell (S) alleles are maintained in places where malaria disease is common? (Hint: Use the attached reading).

Sickle Cell Anemia and Malaria (Extra reading for explanation question b)

In the United States, about 1 in 500 African-Americans develops sickle cell anemia. In Africa, about 1 in 100 individuals develops the disease. Why is the frequency of a potentially fatal disease so much higher in Africa?

The answer is related to another potentially fatal disease, malaria. Malaria is characterized by chills and fever, vomiting, and severe headaches. Anemia and death may result. Malaria is caused by a protozoan parasite (*Plasmodium*) that is transmitted to humans by the *Anopheles* mosquito. When malarial parasites invade the bloodstream, the red cells that contain defective hemoglobin become sickled and die, trapping the parasites inside them and reducing infection.

Compared to AS heterozygotes, people with the AA genotype (normal hemoglobin) have a greater risk of dying from malaria. Death of AA homozygotes results in removal of A alleles from the gene pool. Individuals with the AS genotype do not develop sickle cell anemia and have less chance of contracting malaria. They are able to survive and reproduce in malaria-infected regions. Therefore, BOTH the A and S alleles of these people remain in the population. SS homozygotes have sickle cell anemia, which usually results in early death. In this way, S alleles are removed from the gene pool.

In a region where malaria is prevalent, the S allele confers a survival advantage on people who have one copy of the allele, and the otherwise harmful S allele is therefore maintained in the population at a relatively high frequency. The frequency of the S allele in malaria-infected regions of Africa is 16%. The sickle cell allele is also widespread in the Mediterranean and other areas where malaria is or used to be a major threat to life. In contrast, the S allele frequency is only 4% in the United States, where malaria has been virtually eliminated. Malaria was once common in the United States, but effective mosquito control caused the number of cases to drop. Recently, however, there has been an increase in the number of malarial cases because of increased travel, immigration, and resistance to medication. In Southern California there was a 1986 outbreak of nearly 30 cases of malaria transmitted by local mosquitoes!

Sickle Cell Anemia and Current Research

The oxygen requirements of a fetus differ from those of an adult, and so perhaps not surprisingly, prenatal blood contains a special hemoglobin. Fetal hemoglobin contains two gamma (g) globin polypeptide chains instead of two adult b chains. After birth, the genes encoding g globin switch off, and the ones encoding b globin switch on. Understanding how this genetic switch works could allow researchers to understand much about the control of genes in general and sickle cell anemia in particular.

Indian and Saudi Arabian people have a milder variation of sickle cell anemia, sometimes with no symptoms. In this population twenty-five percent of each person's hemoglobin is the fetal kind. Similarly, the blood of adults with an inherited condition called "hereditary persistence of fetal hemoglobin" also contains fetal hemoglobin and these individuals are healthy. Some people with this condition completely lack adult hemoglobin and still show no ill effects. Biochemical experiments have demonstrated that, in a test tube, fetal hemoglobin inhibits polymerization of sickle cell hemoglobin. These observations suggest that increasing fetal hemoglobin levels may

be an effective treatment for sickle cell anemia. There are a number of lines of research related to activation of fetal hemoglobin as a therapy for sickle cell anemia:

- Some infants whose mothers suffered from diabetes during pregnancy have unusually high concentrations of the biochemical butyrate in their blood plasma. Butyrate is a natural fatty acid that stimulates RBCs to differentiate from their precursors (reticulocytes). Butyrate also prevents the γ globin gene from switching off and the β globin gene from switching on in these infants, who are healthy despite lacking adult hemoglobin. When butyrate is given to patients with sickle cell anemia, the γ globin mRNA levels in reticulocytes increase significantly. Perhaps butyrate or other chemicals that stimulate fetal hemoglobin production could be used to treat sickle cell anemia.
- In 1983, a drug called hydroxyurea (HU) was first used on sickle cell patients to try to activate their fetal globin genes. By 1995, clinical trials had demonstrated that HU could increase fetal hemoglobin levels in patients' RBCs and prevent the cells from sickling. Patients treated with HU experienced less frequent and severe painful crises. However, hydroxyurea can be quite toxic when used continuously to maintain elevated levels of fetal hemoglobin and can increase the risk of leukemia.
- In 1992, it was found that alternating hydroxyurea with erythropoietin and providing dietary iron raised the percentage of RBCs with fetal hemoglobin and relieved the joint and bone pain of sickle cell disease. Erythropoietin is made in the kidneys and helps anemic patients replenish their RBCs. It can be manufactured for therapeutic use with recombinant DNA technology.
- Mice that have been genetically engineered to contain a defective human β globin gene have symptoms typical of sickle cell anemia, making them an ideal model for laboratory experimentation. In 2000, these mice were mated to another transgenic mouse line expressing human fetal hemoglobin. When compared to their sickle cell parents, the offspring had greatly reduced numbers of abnormal and sickled RBCs, increased numbers of RBCs overall (reduced anemia), and longer lifespan. These experiments established that only 9-16% of hemoglobin need be the fetal type in order to ameliorate the sickle cell symptoms, and are an important first step in a gene therapy solution to sickle cell disease.

Reference: Genetics Education Partnership. Sickle Cell Anemia: *A case study approach to teaching high school genetics*. Retrieved from: <http://genetics-education-partnership.mbt.washington.edu/download/file.html>

Science Letter Writing:

You mother's friend Anna has just learned that she is pregnant. A second test indicated that there was a risk for her baby to have sickle cell anemia. She and her husband have never had sickle cell anemia. So she does not understand how her baby can have sickle cell anemia.

Fortunately, you just learned about the genetics of sickle cell anemia. You want to share your knowledge regarding this with Anna in a letter.

Now, in your letter explain the following:

How can parents who have never had sickle cell anemia, have a baby with sickle cell anemia? What combination of parental genotypes will cause the baby to have sickle cell anemia? Based on this combination, what is the percentage of having a sickle cell anemia baby for these parents?

In your answer use the following terms, genotype, phenotype, homozygous, heterozygous, and allele.

Grading rubric:

Clarity of writing: 20

Appropriate use of terms: Genotype, Phenotype, Homozygous, Heterozygous, Allele:

5x5=25

Correct answer to parental genotypes: 15

Correct answer to percentage of having sick baby: 15

Overall consistency and logic of your argument: 25

Evolution Lab

Name: _____

Date _____ Ntbk # _____

Purpose: Students will investigate whether apes are common ancestor of human beings.

Problem: What is the relationship between humans and chimpanzees and gorillas?

Research: Four groups of organisms included in Apes family are gibbons, chimpanzees, gorillas, and orangutans. Chimpanzees and gorillas represent the African side of the family; gibbons and orangutans represent the Asian side of the family. In this activity we will focus only on the chimpanzee and gorilla. In table 1, you can see a comparison of characteristics of humans and apes. The only modern representative of the human family is *Homo sapiens*, although paleontologists have found fossil remains of other members, such as *Australopithecus afarensis* ("Lucy") and *Homo sapiens neandertalensis*.

Diagrams called branching trees illustrate relationships among organisms. One type of branching tree, called a morphological tree, is based on comparisons of skulls, jaws, skeletons, and other structures. Look carefully at the morphological tree in Figure 1.

Getting Ready for Hypothesis: Think about different animals that you think they are relatives. Give some examples and tell why do you think they are relatives? (5 points).

Hypothesis: Looking at the Figure 1, find the part of the morphological tree that shows gorilla, chimpanzee and humans. Make three possible hypotheses that show the ancestral relationship among gorilla (G), chimpanzee (C), human (H), and a common ancestor (A). Express your hypotheses in morphological tree figures. (It is important to make hypotheses here, because later you will test your hypotheses) (9 points).

Experiment/Procedures:

1) Working in groups of four, "synthesize" strands of DNA according to the following specifications. Each different color of paper clip represents one of the four bases of DNA:

blue = adenine (A) green = guanine (G)

white = thymine (T) red = cytosine (C)

Synthesize your DNA strands by connecting paper clips in the proper sequence according to specifications listed for each group member. When you completed the synthesis, attach a label to Position 1 and lay your strands on the table with Position 1 on the left.

- Group member 1

Synthesize a strand of DNA that has the following sequence:

Position 1

Position 2

A-G-G-C-A-T-A-A-A-C-C-A-A-C-C-G-A-T-T-A

Label this strand "human DNA." This strand represents a small section of the gene that codes for human hemoglobin protein.

- Group member 2

Synthesize a strand of DNA that has the following sequence:

Position 1

Position 20

A-G-G-C-C-C-C-T-T-C-C-A-A-C-C-G-A-T-T-A

Label this strand "chimpanzee DNA." This strand represents a small section of the gene that codes for chimpanzee hemoglobin protein.

- Group member 3

Synthesize a strand of DNA that has the following sequence:

Position 1

Position 20

A-G-G-C-C-C-C-T-T-C-C-A-A-C-C-A-G-G-C-C

Label this strand "gorilla DNA." This strand represents a small section of the gene that codes for gorilla hemoglobin protein.

- Group member 4

Synthesize a strand of DNA that has the following sequence:

Position 1

Position 20

A-G-G-C-C-G-G-C-T-C-C-A-A-C-C-A-G-G-C-C

Label this strand "common ancestor DNA." This DNA strand represents a small section of the gene that codes for the hemoglobin protein of a common ancestor of the gorilla, chimpanzee, and human.

(Important note: The first three DNA strands above are real, but the last one is not real. There is not a common ancestor DNA identified for gorilla, chimpanzee, and human yet. However, in our experiment we are using a model constructed from hypothetical data in the case of the common ancestor.

2) Compare the human DNA to the chimpanzee DNA by matching the strands base by base (paper clip by paper clip). Count the number of bases that are not the same. Record your data in a table. (Draw your table to under data/observations section)

3) Compare the human DNA to gorilla DNA. Count the number of bases that are not the same. Record your data in the table.

4) Compare the common ancestor DNA to all three samples of DNA (gorilla, human, and chimpanzee), one sample at a time. Record the data in a different table.

Data/Observations: Draw your tables below (6 points).

Analysis and Conclusion:

1) a) What claims can you make when you compare the human DNA to chimpanzee DNA and gorilla DNA? Which one of those apes is closer to humans? (10 points)

b) What claims can you make about the relationships among the common DNA ancestor and other DNAs (human, chimpanzee, and gorilla)? Which DNA is most similar to common ancestor DNA? (10 points)

c) Which one of the hypotheses you made supports your claims? Draw the figure of hypothesis you think it is true. (10 points)

2) What evidence do you have to support your claims? How do you know that your claims are true? What evidence support you final hypothesis? (20 points)

Evidence for claim a)

Evidence for claim b)

3) Based on the hypothesis that your data best supported, which of the following statements is most accurate? Explain your answer in a short paragraph. Build your explanation upon the data and evidence you collected, and use the morphological tree model to support your explanation (15 points).

- a) Humans and apes have a common ancestor.
- b) Humans evolved from apes.

4) Using the same instructions on question 3, which one of the following statements is most accurate? (15 points).

- a) Chimpanzees are the direct ancestors of humans
- b) Chimpanzees and human have a common ancestor.

Fungi Lab

Name: _____

Date _____ Ntbk # _____

Purpose: Students will observe the growth of fungi on different food sources and explain how different conditions stimulate or inhibit fungi growth.

Problem: How does different environmental conditions affect fungi growth?

Research: Fungi are eukaryotic, nonphotosynthetic organisms, and most are multicellular heterotrophs. Most fungi are microscopic molds or yeasts. Molds, such as the fungus that grows on bread and oranges, are tangled masses of filaments of cells. Many fungi and molds reproduce mainly by means of microscopic, airborne or waterborne spores. The dormant spores, produced asexually, are virtually everywhere in our environment, including on our food, waiting for an opportunity to germinate and grow. In this investigation, we will explore the growth requirements of the familiar fungi.

Getting Ready for Hypothesis: Name three different food sources that you think likely to grow mold, and explain why do you think so?

Hypothesis: For each pair of environmental conditions given below, make a hypothesis about which environmental condition in that pair provides better environment for fungi growth.

Warmth/cold:

Light/dark:

Propionic acid/Non-propionic acid:

Experiment/Procedures:

- 1) Working in groups of four, get 4 sterile petri dishes of potato dextrose agar.
- 2) Examine your mold samples through a dissecting microscope. Select a dense growth of mold from either a sample you brought from home or one supplied by the teacher.
- 3) Design an experiment to determine which of the two opposite environmental conditions are best for fungal growth for each given pair. In your experiment, use the following opposite conditions: warmth/cold, light/dark, propionic acid/non-propionic acid.
- 4) After you decide in your group how to design your experiment, mark the Petri dishes appropriately for each condition using a grease pen. If necessary, draw a line on the bottom of a Petri dish to divide your Petri dish for two opposite environmental conditions.

- 3) What claims can you make about the fungi grow, when you compare each different pair of conditions. (Remember claim does not need to include the evidence or explanation)

Warmth/Cold:

Light/Dark:

Propionic acid/ Non P.acid:

- 4) What evidence do you have to support your claims?

Warmth/Cold:

Light/Dark:

Propionic acid/Non-P. acid:

- 5) You have everyday knowledge of biology plus you have been studying biology all semester. Based on everything you know about the process of life (such as nutrition, osmosis, cell division, and adaptation), explain why fungi grew better in one of the opposite conditions than the other? Provide explanations for each given pair.

Warmth/Cold:

Light/ dark:

Propionic acid/Non-P.acid:

Leaf Stomata Lab

Name _____

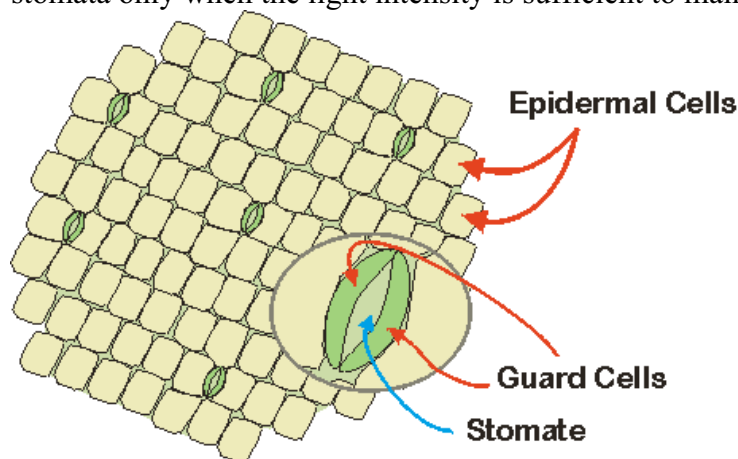
Date _____ Ntbk # _____

Purpose: Students will determine the locations and density of stomata on a leaf, and describe the effect of an environmental change of stomata.

Problem: Where are stomata located on a leaf and how do they work? How does NaCl solution affect guard cells?

Research: Plants obtain carbon dioxide for photosynthesis from the air. Plants must balance their need to open their stomata to receive carbon dioxide and release oxygen with their need to close their stomata to prevent water loss through transpiration.

A **stoma** is a tiny pore in the outer layer (epidermis) of a plant leaf or stem that controls the passing of water vapor and other gases into and out of the plant. A stoma is bordered by two kidney-shaped guard cells. **Guard cells** are modified cells found on the leaf epidermis that regulate gas and water exchange. When the stomata are open, carbon dioxide can enter the leaf by diffusion, but water vapor may also be lost in the same way. Closed stomata prevent water lost but also exclude carbon dioxide from the leaf. Most plants compromise by opening the stomata only when the light intensity is sufficient to maintain a good rate of photosynthesis.



Getting Ready for Hypothesis: (5 points)

Imagine you are a plant, and you are in a very hot, sunny day. There is lots of sunshine, and it is a good day to photosynthesize and make some food. However, you are very thirsty and it has been quite drought during the week. What are the things you need to consider as a plant, when there is little water and you want to photosynthesize?

Hypothesis: (5 points)

Make hypothesis about how would guard cells respond to a salt (NaCl) solution?

Experiment and procedures:

- 1- Place a drop of water on a microscope slide. Obtain a healthy, nonwilted leaf from one of the available plants. Holding the bottom surface of the leaf toward you, fold the leaf in half toward you so that the bottom surfaces are together. Unfold the leaf and tear it along the crease by holding the left section of the leaf and pulling the right section down at an angle. A clear, colorless outer layer should be visible along the torn edge. **This layer is the lower epidermis.**
- 2- Carefully cut off a small fragment of the transparent epidermal layer with a razor blade or pull it off carefully with forceps. Immediately place the fragment in the drop of water on your microscope slide and position a coverslip over it. Do not allow the fragmentation to dry out.
- 3- Examine the epidermis through the low-power objective of your microscope. Observe the sizes and shapes of the living cells in the epidermis. The small bean-shaped cells occurring in pairs are guard cells. Make an outline drawing of a pair of guard cells and the surrounding epidermal cells in the space provided under observations section.
- 4- Examine the pair of guard cells under the high power objective. The opening or pore visible between the guard cells is stomata.
- 5- Return the microscope objective to low power. Record the number of stomata that you observe in your data chart.
- 6- Repeat steps 1 through 5 with another leaf from the plant you have been using, but this time examine **the upper epidermis**. Holding the top surface of the leaf toward you, fold the leaf in half toward you so that top surfaces come together. Record the number of stomata that you observe in your data chart. Then tear the leaf along the crease as you did in step 1, to obtain a fragment of upper epidermis.
- 7- Make a fresh wet mount of the lower epidermis of a leaf. Observe a stoma under high power. Place a drop of 5% NaCl solution as the edge of the coverslip. Take a piece of paper towel and touch it to the opposite edge of coverslip. The paper towel should draw out the water that bathes the epidermis, and the NaCl solution should replace the water. This will create a concentration gradient between the cells and their environment. Water will move out of the guard cells by osmosis until the salt concentration inside the cells is the same as it is outside. Allow 5 minutes for osmosis to be completed, and then observe the guard cells and stomata again.

Data/Observations:

Number of Stomata Observed	
Lower epidermis	
Upper epidermis	

1) a) What did you see when you observed lower epidermis under microscope? Draw your illustration below (15 points).

b) What happened to the guard cells and stomata after you applied NaCl solution? Provide as many details as you can (15 points).

Conclusion and Analysis:

1) What claims can you make about the effects of NaCl solution on leaf guard cells and stomata? (15 points)

2) What evidence do you have to support your claim? (How do you know that your claim is right?) (15 points).

3) a) Explain why it is an advantage for a plant to have most of its stomata on the underside of a horizontal leaf? (15 points)

b) Explain how guard cells respond to hot and dry conditions? How might this affect photosynthesis? Why? (15 points)