# THE DISCOURSE OF CAUSAL EXPLANATIONS IN SCHOOL SCIENCE

by

TAMMY JAYNE ANNE SLATER

B.A. (Honours), University of Victoria, 1986
M.A., University of British Columbia, 1998

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# ABSTRACT

Researchers and educators working from a systemic functional linguistic perspective have provided a body of work on science discourse which offers an excellent starting point for examining the linguistic aspects of the development of causal discourse in school science, discourse which Derewianka (1995) claimed is critical to success in secondary school. Yet the work that has been done from this perspective has generally focused on texts in science books and encyclopedias, or in other words, texts written by expert writers (e.g., Mohan et al., 2002; Veel, 1997). A notable exception is Gibbons (1998, 2003), who used data from an elementary ESL science class to illustrate the move from hands-on, context-dependent discourse to the decontextualized forms characteristic of science writing, and the role of the teacher in providing the necessary scaffolding to make this move successfully. No work has yet described the development of causal language by identifying the linguistic features present in oral discourse or by comparing the causal discourse of native and non-native (ESL) speakers of English.

The current research responds to this gap by examining the oral discourse collected from ESL and non-ESL students at the primary and high school grades. Specifically, it asks the following questions:

1. How do the teachers and students in these four contexts develop causal explanations and their relevant taxonomies through classroom interactions?
2. What are the causal discourse features being used by the students in these four contexts to construct oral causal explanations?

Ethnographic data collection involved recording observations of classroom interactions (244 recorded hours) as well as formal and informal interviews (9+ hours), which were transcribed and coded to reveal (1) how the teachers built up key concepts through their implementation of the two types of linguistic patterning which Halliday (1998) claimed is involved in constructing science knowledge—the creation of technical terms and chains of logical reasoning—and (2) the causal discourse features which were used by the students to construct their explanations. A social practice analysis revealed the similarities and differences which existed among the four contexts studied with regard to the teachers' ways of developing the ability to explain and construct science knowledge, and a small corpus study helped to show the patterns of development across the same four contexts. Concept maps (Novak, 1998), built from the

discourse of the classroom interactions, offered graphics to illustrate the knowledge which was constructed through the classroom discourse.

The findings of the social practice analysis showed that the teachers in the four contexts differed in their approaches to teaching, with the primary school mainstream teacher focusing largely on the hands-on *practice,* the primary school ESL teacher moving *from practice to theory,* the high school mainstream teacher moving *from theory to practice,* and the high school ESL teacher relying primarily on *theory.* Although no causal connections can be made from this study regarding the effectiveness of one approach over another, the findings appear to reflect the popular practice of using hands-on, minds-on approaches to teaching and learning science. The study therefore contributes a new, linguistic perspective to work which has been and continues to be carried out in science education.

The findings from the quantitative, small corpus approach suggest that the developmental path of cause which has been identified in the writing of experts shows up not only in written texts but also in the oral texts which learners construct. Moreover, this move appears when the discourse of high school ESL and non-ESL students is compared, suggesting a developmental progression in the acquisition of these features by these students. The findings also reveal that the knowledge constructed, as shown by the concept maps created from the discourse, follows a developmental path similar to the linguistic causal path, from the concrete, hands-on, observable items to more abstract, theoretical concepts.

This study is the first systemic functional comparison of the oral discourse of primary and secondary learners as well as the first to compare ESL and non-ESL speakers in this way, and as such it helps map general trends in causal discourse development.

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# CHAPTER 1: INTRODUCTION

## 1.0 Why causal explanations?

The language of cause and effect permeates almost every academic subject in school, particularly in the upper grades. English literature classes, for example, require students to explain the motivation of characters in works of literature. Discussions in social studies classes revolve around the examination of effects and consequences of various events in history. In science, hypothesizing, predicting, and experimenting clearly involve relations of cause and effect. Painter (1999) maintained that "the ability to infer cause-effect relations is fundamental to notions of 'logical' or 'scientific' thinking, and the fostering of the abilities to reason and hypothesize are prominent educational goals throughout the Western world" (p. 245). Yet causal language, according to Halliday and Martin (1993) is characterized by grammatical metaphor, which is "fundamental to adult uses of language" (Halliday & Matthiessen, 1999, p. 7) and which children typically only begin to handle well at around thirteen years of age. Since this indicates a potential developmental issue, research into causal explanations is important for the purpose of language education, both for native speakers of English and for English as a second language (ESL) students.

This study focuses on causal explanations in science, rather than in other disciplines, because of the existing knowledge base in the field. As this chapter will introduce and Chapter Two will detail, there is a solid foundation which can be used to drive theory forward. Most of this has explored causal explanations in science texts written by experts in language and content; thus the results offer a starting point for examining oral causal explanations constructed by learners, both students of English as their first language and ESL learners. Both groups in this study are learning how to construct causal explanations in science using English, and by holding their discourse up to that written by experts, it may be possible to explore more fully any developmental trends in the acquisition of this form of academic language.

## 1.1 Causal explanations as part of science content

The Integrated Resource Packages (IRPs) for science, developed by the Curriculum Branch of the British Columbia Ministry of Education, aim to provide "a framework of opportunities for students to become scientifically literate" (e.g., British Columbia Ministry of Education, 1995a, 1995b). According to Karplus and Thier (1967), to be considered scientifically literate, "the individual must have a conceptual structure and a means of communication that enables him to interpret the information as though he had obtained it himself" (p. 24). Norris and Phillips (2003) argued that the ability to handle science text is critical to learning and understanding science, and that therefore literacy in its most fundamental sense is central to scientific literacy, although oracy in science "plays an irreplaceable role in the development, critique, and refinement of scientific thought" (p. 233).

Throughout the British Columbia Ministry web pages, the IRPs advocate developing science skills and processes which are "the same as those used by scientists at work." Students are expected to develop the knowledge, skills, and attitudes necessary for scientific literacy by "working scientifically," "communicating scientifically," "using science," and "acting responsibly." According to the IRPs, these four processes involve such language functions as *asking questions, explaining, defending opinions, discussing limitations,* and *defining problems,* thereby suggesting that language is a main component of science instruction. A brief glance at the learning outcomes for all grade levels further demonstrates the importance of language, as many of those outcomes involve verbs such as *describe, communicate, explain, discuss, suggest,* and *debate*. Moreover, the IRPs for all grades list such skills as *observing, predicting, controlling variables, measuring, communicating, interpreting data, classifying, hypothesizing, formulating models, designing experiments,* and *inferring,* many of which involve the explicit use of language, as "central to the presentation of all content and the delivery of instruction and assessment activities in classrooms." As inferred from these Ministry documents, language is certainly a key part of science education, but how is language—particularly causal language—being developed in science classrooms?

## 1.2 Teaching causal explanations from the science educators' perspective

In the past, language development in science tended to focus primarily on technical terms; after all, as O'Toole (1996) noted, specialist vocabulary tends to be the most noticeable feature of scientific English, and as the Classical Component of the 1991 British Columbia Assessment of Science stated, "an understanding of scientific terminology is necessary for further investigations to take place" (Bateson et al., 1992, p. 169). Yet it has become more recognized that learning to talk science "runs rather deeper than 'simply' learning to articulate the words and phrases of a new speech genre" (Scott, 1998, p. 74), and several recent articles have listed the typical characteristics of science language which make it problematic for students (e.g., Buck, 2000; Carlson, 2000; Simich-Dudgeon & Egbert, 2000). Although an interest in the use of analogy and metaphor to explain scientific concepts has surfaced (Ogborn, 1996), science educators in general have not paid much attention to the nature or use of explanation in their teaching (Lawrence & Pallrand, 2000), and "'explanation' still remains a largely unexplicated notion" (Ogborn, 1996, p. 159). Moreover, even though many authors have advocated the explicit teaching of science language (e.g., Henderson & Wellington, 1998; McGinn & Roth, 1999; McKeon, 2000; O'Toole, 1996; Prophet & Towse, 1999; Ritchie & Tobin, 2001; Yore, Craig, & Maguire, 1998; Zohar & Ginossar, 1998), causal discourse as a key element of scientific explanations has not been addressed. Where causal reasoning in science has been explored (e.g., Borges & Gilbert, 1999, who concluded that more detailed studies of sequential and causal reasoning need to be done), the focus has been on conceptual understanding, and the role language plays in this has not been elaborated on. In fact, the general view throughout science education journals is that it is the science teacher's task to facilitate the acquisition of science concepts; language is recognized as playing a role in this, but conceptual understanding is the primary interest. This recognition is revealed in a comment by Roth (1998), who noted that concepts can be viewed "as the patterns in the language employed by students to describe and explain their science-related experiences, and conceptual change is the change in these descriptions and explanations" (p. 1020). Although students are expected to advance their conceptual understanding and to demonstrate that understanding orally and in written form, causal language development in science classes has not yet been targeted as an area deserving explicit attention.

## 1.3 Teaching causal explanations from the language educators' perspective

Causal language development from the language educators' perspective is surprisingly superficial. From a brief inspection of current popular English as a second language (ESL) textbooks such as the *Interchange* series (Richards, Hull, & Proctor, 1991) and the *Canadian Concepts* series (Berish & Thibaudeau, 1998), or English for Academic Purposes (EAP) textbooks (e.g., Campbell, 1995), or Azar's (2000) English grammar *Chartbook*, causal discourse appears to be limited to isolated lexical items such as the causative verbs *make, have,* and *get,* and various causative connectives such as *because, consequently, since,* and *if.* The writing of cause and effect discourse is concentrated in only four pages of Swales and Feak's *Academic writing for graduate students: A course for nonnative speakers of English* (1994). Causal discourse in reference books for native English speakers do not fare much better, and very few articles on the topic have appeared in journals, which is surprising given that causal explanations seem to play such a key role in academic discourse. One exception is Cronnell (1981) who, in a piece dedicated to an overview of cause and effect language, stated that an understanding of cause-effect relations was one factor among many which lead to good reading comprehension. He stated that these relations were common in discourse, but could be quite complex and therefore could pose problems for young readers. His article described "the various kinds of cause-effect relations and constructions that readers must be familiar with in order to comprehend effectively" (p. 155). In eleven pages, Cronnell listed all the examples of cause and effect that he considered necessary to introduce; all the examples offered were either lexical items as in the textbooks or adverbial clause constructions.

Mohan (1997) and Mohan and van Naerssen (1997) criticized this sentence-level view of causal discourse as being inadequate for academic language development. Using student recalls of a cause and effect reading passage from a social studies unit, both articles argued that causal meanings are constructed using a combination of rich lexical and grammatical resources and that for students to be able to understand and produce academic discourse, they need to be aware of the subtleties of causal meanings and how to construct them. The development of causal language was the topic of Mohan and Beckett (2001), who illustrated how the interaction between a teacher and a university-level ESL student in a project-based language classroom led to the student's use of more literate, academically valued language. Causal language, as Mohan and Beckett showed, is an important part of academic language, and yet the textbooks which teach language explicitly, as noted above (see also Flowerdew, 1998), do not go much beyond the sentence-level treatment which Mohan criticized. Little work has been done to explore how these meanings are constructed in science discourse; consequently, little work can be offered to inform the language-teaching textbooks.

### 1.4 Teaching causal explanations in language and content classrooms

Because it has been recognized that non-English-speaking students who arrive in English schools cannot wait until they speak the language fluently before beginning content instruction, much of the work in the combined language and content teaching research has focused on strategies which help reduce the linguistic demands so that these students can access the academic content they need to learn while simultaneously learning English (for a concise discussion of content-based instruction, see Crandall, 1999; for examples of work in the area, see Snow & Brinton, 1997). Although simplifying the language of instruction has been recommended by some authorities (e.g., British Columbia Ministry of Education, 1999), several educators have instead advocated using graphics to help trigger existing knowledge structures and to show the underlying conceptual relationships in the content (e.g., Carlson, 2000; Early & Tang, 1991; Mohan, 1986, 2001; Tang, 1992, 2001). As Mohan (1986) stated:

> Much of academic knowledge is knowledge of relations, and these relations can be, and often are, represented by graphics. If learners are able to interpret these graphics, they have easier access to the knowledge represented. (p. 90)

Moreover, each knowledge structure visually captured by the graphic, according to Mohan, has specific language associated with it which can be used to construct the discourse of the knowledge structure.

Working from Mohan's framework, Early and Tang (1991) reported on a procedure for supporting students' academic reading through key visuals. Tang (1992, 2001) further showed how a social studies unit was presented using these visuals, and how the cause-effect graphics led to student compositions of causal texts. The teacher in Tang's study had to provide the student with the linguistic items of cause and effect, but the resulting student-generated text was a coherent passage. Carlson (2000) presented ideas for and examples of various key visuals that are useful for teaching science concepts in a way that makes the language accessible.

Research has shown, however, that the same key visual can produce very different texts. Slater (1998) demonstrated how a visual representation of the water cycle generated a wide variety of text types, and even within the same category of causal explanation, different explanations were judged to be more or less academically literate. What this suggests, then, is that an individual's ability to construct causal meanings may be related to the overall depth or breadth of his or her linguistic resources. Supporting this idea, Mohan (2001) noted that there is a major contrast between skilled and unskilled writers working with the same information. This highlights the importance of looking at resources for causal discourse as academic discourse and reinforces Mohan's observation that sentence-level treatments of causal discourse, although perhaps useful initially, are inadequate for the development of academic language. A closer examination of the topic is very much needed.

### 1.5 Purpose of the study

Given the importance of causal discourse in academic language development as stated above, the present study has been designed to explore the construction of oral causal explanations by ESL and non-ESL students in primary and high school science classes. Specifically, it aims to examine how teachers and their students develop causal explanations in four contexts of school science, and which linguistic resources the students in each of these four contexts use to explain their understanding of cause and effect relationships. It is not the purpose of this study to judge the adequacy or inadequacy of the participants' understanding of science concepts; such a task demands the skills of a science educator.

This study also proposes to examine the role which grammatical metaphor plays in the development of causal explanations in these four contexts, and hold this up to previous research on the topic. According to Halliday and Martin (1993), grammatical metaphor is similar to lexical metaphor in that both involve linguistic transformations, but "instead of being a substitution of one *word* for another,... it is a substitution of one grammatical class, or one grammatical structure, by another" (p. 79, italics in original). Acquiring an ability to use this linguistic resource is a critical step in becoming socialized into an academic discourse community because "articles written for specialists typically display a considerably denser concentration of grammatical metaphor" (p. 14). If it is indeed the goal of science education to apprentice students into the scientific discourse community (McGinn & Roth, 1999; Ritchie & Tobin, 2001), it is necessary for educators to understand the role grammatical metaphor plays in science language and how it can be developed in science classrooms.

The study also responds to the more general need for exploring how teachers and learners construct meaning together. In a book devoted to conversational analysis, Markee (2000) claimed that in the field of second language acquisition, theory has "far outstripped empirical verification" about how "second language (L2) learners use talk to learn new language" (p. 13). This study aims to provide empirical data which address how teachers and students are using (or not using) talk to develop resources for causal explanations in science classrooms.

### 1.6 Research questions

This study takes a systemic functional linguistic perspective on language, using discourse analysis and concordancing techniques to examine how the participants in four different contexts construct causal explanations. The four contexts reflect different populations (ESL and non-ESL speakers) and different age groups (six to eight years old and fourteen to sixteen years old). The questions which guide this examination of the four contexts are as follows:

1. How do the teachers and students in four distinctively different contexts—primary and high school ESL and non-ESL classes—develop causal explanations and their relevant taxonomies through classroom interactions?

2. What are the causal discourse features being used by the students in these four contexts to construct oral causal explanations?

The first question is addressed primarily through a discourse analysis of the classroom interactions using observation data (orally recorded data and field notes). The second question is responded to by looking closely at interviews with students from the four contexts and quantifying the causal discourse features they used in their explanations.

## 1.7 Significance of the study

This study is significant in a number of ways. First, it brings together science education and language education and informs teachers and teacher educators about the linguistic resources children use to explain their views of the world. Science educators have typically focused on children's conceptions or misconceptions about science, not attending to the linguistic resources which the child uses to construct those (mis)conceptions and therefore not realizing the potential that science has for developing the child's academic language ability. Sutman (1996) argued that teacher education programs typically do not take the language and science connections into consideration, saying that "too often, the professional practices of teachers ignore the role in science education for language development beyond memorization of science vocabulary" (p. 460). This study aims to show how language development occurs alongside the development of science concepts.

Second, as Martin (1972) pointed out, science textbooks frequently require students to explain, yet there has been little systematic inquiry into what acceptable scientific explanations are. More recently, Nieswandt (2001) also raised the question of what constitutes a good explanation at a given level. Brewer, Chinn, and Samarapungavan (2000) noted that "people have relatively clear intuitions about what is or is not an explanation and that these intuitions serve as the foundation of most discussions of explanations" (p. 279). Added to that comment is an observation by Keil and Wilson (2000) that "there are also compelling intuitions about what makes good explanations in terms of their form" (p. 1). Gilbert, Boulter, and Rutherford (1998) reviewed the literature on teachers' understanding of the principles of explanation and concluded that relatively few studies have been carried out in the area. As Ogborn (1996) stated, "giving a better, clearer and fuller account of what explaining is in the science classroom is a current task of urgency and importance" (p. 159). Although this study cannot make judgments about the scientific adequacy of explanations, it can offer science educators a description of the linguistic resources exploited by children constructing causal explanations at two distinct age levels. As far as the researcher knows, a study such as this has not yet been undertaken.

Third, although science educators and researchers have frequently observed differences in the ways children "talk science" and have noted that their everyday language is not adequate for learning and explaining science (e.g., Ebenezer & Erickson, 1996; Levine & Geldman-Caspar, 1997; Moje, Collazo, Carillo, & Marx, 2000; Nieswandt, 2001), these comments have typically been left at the level of observation and a systematic analysis of this language has not been carried out. Many science educators assume that what poses problems for children learning science are aspects of the vocabulary (e.g., Allie, Buffler, Kaunda, Campbell, & Lubben, 1998; Carlson, 2000; Prophet & Towse, 1999). Because this study aims to shed light on how children construct causal explanations in science, it can examine the connections between "vocabulary" and "grammar" in children's developing linguistic ability and thereby offer information about these connections and how they relate to everyday versus science language.

Fourth, whereas there have been several research projects which have examined how teachers help construct scientific understanding through oral discourse in the classroom (e.g., Driver, Leach, Millar, & Scott, 1996; Lemke, 1990; Ogborn, Kress, Martins, & McGillicuddy, 1996), these studies involved students who were not designated English as a second language (ESL) students and the focus was on concept development rather than language development. Gibbons (1998, 2003) examined ESL students studying magnetism and argued the importance of teacher scaffolding in developing the children's ability to handle academic discourse. Aside from Gibbons's studies, the researcher is not aware of any other projects undertaken in ESL science classrooms with a focus on language development. Language development is the aim of both the science and the language educator (although it seems that science educators rarely acknowledge this), but it is an explicit goal of ESL science classes where teachers must prepare students for mainstream classes while continuing to teach grade-appropriate science concepts. Because the present study involves ESL science classrooms, it can inform the field of second language acquisition by offering a description of the causal language used by ESL students in content-based language classes.

Fifth, in their research of students' ideas about the nature of science, Driver, Leach, Millar, and Scott (1996) developed a framework of three types of student-generated explanations which the authors suggested may be developmental. The present study is significant because it will add to their information by highlighting potential developmental patterns in the explanations of both native and non-native speakers of English.

Sixth, this study is significant because it offers insight into the kind of academic science language used to construct causal explanations at widely differing age levels. It has been suggested that the ability to deal with grammatical metaphor, a key aspect of academic discourse, begins at about the time students enter grade eight (Halliday & Martin, 1993), but the discussion of grammatical metaphor has so far been concerned with speakers whose first language is English. Because this study deals with ESL students as well as with students whose first language is English, the findings will add greatly to the second language acquisition knowledge base through its exploration into potential differences between the two age levels under investigation with respect to grammatical metaphor. As far as the researcher knows, the only work that has been done connecting grammatical metaphor and second language development is Mohan and Beckett (2001), which focused on university-level students. The present study should add to this by showing similarities and differences in the use of grammatical metaphor and academic language use between the causal explanations composed by ESL students and those of non-ESL students at two contrasting age levels.

Seventh, it is now a commonly held view that it takes second language learners five to seven years to achieve what Cummins (1984) referred to as Cognitive Academic Language Proficiency (CALP). Because this study aims to examine causal explanations produced by ESL and non-ESL speakers at the high school level and analyze the similarities and differences between these two groups, the findings may make it possible to single out key aspects of causal language development which teachers can focus on to facilitate students' academic language development across the curriculum. Developing academic language quickly is especially important for the high school age group, which has limited time left to acquire the language necessary to graduate successfully from grade twelve. Furthermore, knowing which areas to focus on may make it easier to respond to Derewianka (1995), who recommended research into teacher intervention in the development of grammatical metaphor in children's language.

Finally, as noted in the previous section, this study is significant because it addresses the general need as outlined by Markee (2000) for more empirical verification of how students, particularly ESL students, talk to learn in academic settings.

## 1.8 Theoretical background

Because the researcher's world view influences the questions asked and shapes how the data are collected, analyzed, and presented (Creswell, 1994; Merriam, 1988; Mertens, 1998), it is important to summarize these perspectives as they relate to the study being undertaken. This section will therefore review theories of causality, language, learning, and research, and situate the present study within these theories.

### 1.8.1 Theories of causality and causal explanations

Over the years there have been a number of books written on the topic of causal explanations and causality, and it is not the intention to offer a thorough review here. It is, however, important to offer a brief summary of the ideas held by the researcher as her views may influence the way she selects, interprets, and presents the data.

A well-used example of causal theory is Hume's billiard ball example in which ball A strikes ball B, setting it in motion while potentially ceasing its own. The causal relationship between these two balls is not something directly observable: "What we actually observe is one event followed by another event" (Searle, 1983, p. 112). This view, which highlights the consistency of events occurring in a temporal sequence, is referred to as regularity theory (Harré & Madden, 1975). This regularity theory can be contrasted with the power theory, which attributes power to an agent in a causal relationship. Harré and Madden explained the differences in the two views by discussing sedation: Whereas holders of a regularity view of causality would explain that an individual "has been put to sleep by opium because all or most cases of opium taking have regularly been followed by sleep" (p. 85), those holding a power view would look to the nature of opium itself. These two views reflect different perspectives on causality, and the language the individual chooses to construct an explanation may reflect either of these views.

As suggested above and closely related to the regularity and power theories is the notion of agency. Harré (1993) raised the question of whether humans are "active agents using their social knowledge jointly to accomplish certain ends" or whether they are "information-processing automata, the behaviors of which are the effects of causal processes" (p. 11). Answers which discussed this agent/automata issue are that "persons are not causes, but their actions can be" (Vendler, 1984) and that "causes are *means* and *tools*. People can use them to bring about their effects" (Hausman, 1998). Agent/automata contrasts are apparent in the grammar of English through such pairs as *the boat sailed / Mary sailed the boat* in which the medium and agent are contrasted (Halliday, 1994, p. 164).

Causal explanations in science are often constructed as implication sequences (Halliday & Martin, 1993) or what Hempel (1993) referred to as a genetic explanation in which "each stage must be shown to 'lead to' the next, and thus be linked to its successor by virtue of some general principle which makes the occurrence of the latter at least reasonably probable, given the former" (p. 32). The principle or mechanism which links these events is often not directly observable. Simon (2000) stated that "explanatory theories usually account for phenomena at one level by means of mechanisms drawn from the next lower level of the system structure" (p. 35). Ahn and Kalish (2000) suggested that in the mechanism view of causal explanation, the "mechanism is framed at a different level of analysis that are the cause and the effect. That is, mechanisms involve theoretical constructs that are removed from and underlying the evidential phenomena themselves" (p. 201). Causal explanations, therefore, tend to involve abstract concepts in their linguistic constructions.

Another way of examining the notion of causality is by looking at the conditions which bring events about or prevent effects from occurring. Skyrms (1986) noted that

> the word "cause" is used in English to mean several different things. For this reason, it is more useful to talk about necessary conditions and sufficient conditions rather than about causes.... Being run over by a steamroller is a sufficient condition for death, but it is not a necessary condition. Whenever someone has been run over by a steamroller he is dead. But it is not the case that anyone who is dead has been run over by a steamroller. On the other hand, the presence of oxygen is a necessary condition, but not a sufficient condition for combustion. (1986, p. 84-85)

According to Skyrms, people often use everyday language ambiguously to refer to the cause of something; this ambiguity is unable to distinguish between sufficient and necessary conditions or between the signs and symptoms of the effects. He argued that "the precise language of necessary and sufficient conditions is much more useful than the vague language of cause and effect, sign and symptom" (1986, p. 87).

The last point to be mentioned here is the existence in the biological sciences of anthropomorphic or teleological explanations denoting a sense of causality. These types of explanations contain notions of function, purpose, and intentionality (von Wright, 1971) and are similar to each other in that purpose and intentionality are considered human attributes, yet these goal-oriented outcomes are typically offered as explanations for natural phenomena (Zohar & Ginossar, 1998; Zuzovsky & Tamir, 1999). There are issues regarding the appropriateness and legitimacy of using these types of explanations when teaching and learning science (Lemke, 1990; Taber & Watts, 1996; Zohar & Ginossar, 1998). For a recent review of the types of causality which surface in scientific explanations and the nature of the development of these in children, see Grotzer (2003).

The views in this section suggest that defining *causation* and *causal explanation* may be a difficult task given that philosophers have been debating the meaning of causality and explanation for many years (Kiel & Wilson, 2000; Ogborn, 1996; Salmon, 1998). This study adheres to a definition of causation which follows that of Lakoff and Johnson (1999) and is centrally based on volitional human agency via direct physical force:

> At the heart of causation is its most fundamental case: the manipulation of objects by force, the volitional use of bodily force to change something physically by direct contact in one's immediate environment. (p. 177)

This view of prototypical causation extends to a number of different kinds of causation such as means-end relations. Included in the study's definition is Halliday's distinction between external causation—*a causes x to happen*—and internal causation or proof—*b proves y* or *b causes one to think y* (Halliday, 1993, p. 64). Moreover, the study will adopt the broad definition of a causal explanation proposed by Christie, Gray, Gray, Macken, Martin, and Rothery (1992):

> An explanation is a piece of writing that tells a reader how and why something happens as it does or how and why something is as we find it. (p. 7)

Given that the current research involves oral explanations, however, the word 'writing' in the definition above is understood to mean 'discourse', and 'reader' to include 'listener'.

### 1.8.2 Theories of language

In the field of linguistics there are two primary paradigms: the formalist/structuralist paradigm and the functionalist paradigm (Derewianka, 1999; Halliday, 1994; Martin, Matthiessen, & Painter, 1997; Schiffrin, 1994). The assumptions about the nature of language which each paradigm makes and the way each views language learning and teaching are strikingly different.

### 1.8.3 The formalist/structuralist paradigm: Language as rule

The formalist structuralist paradigm (e.g., Chomsky, 1957, 1965) highlights the form of language by focusing on the universality of rules which allow us to understand and create novel sentences. From this perspective, language development and teaching concerns the individual's ability to acquire and manipulate these rules. Much language instruction, both first language development and English-as-a-second-language (ESL) instruction, targets this manipulation to internalize correct linguistic patterns. Although Chomsky's standard theory of grammar is considered too abstract to be particularly useful in the ESL language classroom, "most instructors… cite the insight into *patterns* of English, into knowing what is rule-governed behavior and what needs to be memorized, into what structures are similar and different, into knowing what goes together as very useful in their teaching" (Paulston, 1998, p. 714, italics in original). In summary, the prominent view from this perspective is that we know a particular language when we know the rules which form the basis of that language (Fromkin, Rodman, Hultin, & Logan, 2001). In other words, the focus from this view is on form.

### 1.8.4 The functionalist paradigm: Language as resource

Rather than seeing language as a biologically or neurologically formed system, linguists working within the functionalist paradigm (e.g., Halliday, 1994) see language as a vast system from which we choose and construct meanings to achieve specific social goals. Functional grammar examines how language has evolved in a particular culture to enable us to accomplish these social goals within that culture. Its focus is on the text as a whole, not on syntax, although smaller units within the text can be highlighted as they relate to the whole text. Systemic functional linguistics (SFL), the functional perspective this research follows, considers that all languages are internally organized into three metafunctions: *ideational,* which allows speakers to represent experience; *interpersonal,* which enables them to set up and maintain relationships; and *textual,* which allows them to create connected, coherent discourse (Christie & Unsworth, 2000).

Because SFL maintains that language is connected to social purposes, text is always interpreted in its context, and context is in turn always a part of the text. There are two inter-related levels of context: context of situation and context of culture. The former is described in terms of *field,* which is the content or topic of the activity; *tenor,* which refers to the nature of the people involved; and *mode,* which refers to the medium used in the situation. These three variables relate to the three metafunctions as field/ideational, tenor/interpersonal, and mode/textual, and each variable draws from the resources available in its accompanying metafunction. The context of culture, according to Christie and Unsworth, also influences language choice in that "cultures evolve recognizable ways by which members can achieve their social purposes in the range of situations they typically experience" (p. 4). These cultural practices—or genres—have their own characteristic text structure, and becoming a member of a particular culture entails learning how to structure appropriate genres, such as a scientific causal explanation, within the context of a particular situation, such as a grade nine science lesson on atoms. Unlike a grammar in the formalist/structuralist view, SFL does not focus on correctness of form, although it does not ignore this aspect, but looks at meanings which are or can be constructed from the resources of the language to meet particular needs in a social/cultural context.

Barker (2001) raised the question of whether Chomsky's theory of universal grammar is simply affording "us all a "lowest common denominator" of verbal expression" (p. 421) and postulated that it is the environment—particularly environments which support reading and writing—which is "responsible for the profound individual differences in thought and consciousness that accompany differences in word usage" (p. 422). This perspective reflects to some extent Halliday's notion of language as a resource for making meaning in that Barker is suggesting that students' resources are expanded by engagement with text and that each student's engagement with the textual environment determines the extent of his or her resources.

To summarize, this study, with its focus on a specific social genre and how its meanings are constructed by members of a particular culture within certain social contexts and interactions, is best approached through the theoretical framework of SFL, which views language as a resource for constructing meaning.

### 1.8.5 Theories of learning and teaching

Over the decades there have been several trends in the field of language learning (Brown, 2000) and of learning in general (Anderson, 2000; Barker, 2001; Bransford, Brown, & Cocking, 1999). Structuralism/behaviorism looked at the observable, breaking it into small units which could be scientifically described and put together again into a whole. Among psychologists, behavior was seen to be something which could be objectively perceived, recorded, and measured. From this paradigm, learning involved being conditioned to respond in certain ways based on positive or negative reinforcement. Anchored to this perspective is the educational practice referred to as transmission which, according to Miller and Seller (1990) is "philosophically allied with an empiricist world view [and] psychologically allied with behaviorism" (p. 56). This position sees knowledge as fixed content which students are expected to learn in contexts which emphasize "direct instructional techniques such as lecture and recitation" (p. 43) and in which the student "merely responds to a structured learning situation" (p. 56). From the transmission position, the purpose of education "is to transmit facts, skills, and values to students" (p. 5), typically using traditional teacher-fronted approaches which see language as a conduit through which this knowledge can be poured.

The view of learning reflected in the Chomskian view of language builds on structuralism, but is not simply interested in the objective measurement of units. From a language perspective within this view of learning, Chomsky's generative-transformation school of linguistics aimed to look beyond a simple description of language to underlying explanations for language acquisition, including notions of innateness and universal grammar. Looking at learning from a psychological view, cognitive psychologists turned to rationalism, looking for reasons to explain why humans behave and learn as they do.

In the later part of the twentieth century, the constructivist paradigm emerged. According to Spivey (1999), "constructivists view people as constructive agents and view the phenomenon of interest (meaning or knowledge) as built instead of passively "received" by people whose ways of knowing, seeing, understanding, and valuing influence what is known, seen, understood, and valued" (p. 3). This paradigm led to a more transactive view of teaching and learning in which "education is viewed as a dialogue between the student and the curriculum in which the student reconstructs knowledge through the dialogue process" (Miller & Seller, 1990, p. 6). Within this constructivist paradigm are Piaget and Vygotsky, who differed in their ideas about the role which social context plays in learning and development. In the words of Cole and Wertsch (1996), "according to the canonical story, for Piaget, individual children construct knowledge through their actions on the world.... By contrast, the Vygotskian claim is said to be that understanding is social in origin" (p. 250). Although the authors argued that this "story" is in dispute, language, as a primary cultural artifact, seems to play a much larger role in Vygotsky's view of learning than it does in Piaget's. Tomasello (1996) noted:

> In general it may be said that Vygotsky accorded to language an active and formative role in intellectual development, as children rallied their cognition

> around the communicative conventions of mature members of their cultures, whereas Piaget always subordinated language to cognition, especially the operative aspects of cognition that derive from children's physical actions on the physical world (later internalized into logical operations carried out mentally). (p. 269)

It is this focus on language and dialogue in the constructivist paradigm that is reflected in the notion of language socialization, a concept articulated by Schiefflin and Ochs (1986; see also Cazden, 1999). This concept views language acquisition as "socialization through language and socialization to use language" (p. 14); in other words, linguistic knowledge is embedded in sociocultural knowledge, and language development is thus seen as socialization into the particular cultural habits and actions of the social group in which the learner is involved. Because it can be argued that the learners in the present study are both learning to use language (being apprenticed into the language used by scientists) and learning through language (using language as a medium to learn science), the language socialization perspective is a useful lens through which to view the discourse interactions regardless of the educational practices (transmission or transaction) which appear to characterize the research contexts.

### 1.8.6 Theories of social science research

According to Mertens (1998), there are three main paradigms in research, each determined by the ontological, epistemological, and methodological assumptions it makes. The first of these paradigms, the dominant one which has for many years guided research in education and psychology, Mertens called *positivism/postpositivism*. Positivists hold the view that there is a truth or reality which awaits discovery and the researcher's job is to "uncover *the* facts and to understand *the* laws or principles that account for those facts" (Palys, 1997, p. 13, italics in original). Postpositivists, on the other hand, argue that although a reality or truth exists, researchers' theories can never prove them; they can only eliminate competing theories, thereby strengthening their own (Mertens, 1998). The reality that positivists and postpositivists aver exists can be held up for experimentation and manipulation, and the experimenter in this paradigm, as Harré (1993) noted, "is to look for correlations between elementary stimuli and elementary behaviours, usually by the use of statistical analyses to identify central tendencies" (p. 14). Quantitative researchers prefer these nomothetic trends and aggregated data. They typically begin with a hypothesis which they then set out to support or refute (the hypothetico-deductive method), and they maintain social distance from those they are researching (Palys, 1997).

The second major paradigm in research, according to Mertens (1998), is the *interpretive/constructivist* paradigm, which covers ethnographic research methodology (e.g., Spradley, 1980). Whereas positivist/postpositivist—or quantitative—researchers deliberately manipulate the contexts or objects they are studying and observe the outcomes of those manipulations, researchers working from this "qualitative" paradigm are concerned with process (Palys, 1997) and attempt to become a non-interfering part of the natural events around them, all the time recognizing that their presence may alter the situation they are observing (Bassey, 1999). The interpretive/constructivist paradigm holds the view that knowledge is socially constructed by the individuals involved in the research process, and that "human beings construct meanings for the events in which they participate" (Griffiths, 1998, p. 36). There is no objective truth or reality; the researcher's goal is to "understand the multiple social constructions of meaning and knowledge" (Mertens, 1998, p. 11). Researchers within this paradigm aim to describe, interpret, or explain social actions within their natural contexts, beginning not with hypotheses which await testing, but with ideas and questions which guide inquiry and build theory from the ground up (Bassey, 1999; Mertens, 1998; Palys, 1997).

The third of the major paradigms which Mertens listed is the *emancipatory paradigm* which "arose because of dissatisfaction with the dominant research paradigms and practices and because of a realization that much sociological and psychological theory had been developed from the White, able-bodied male perspective and was based on the study of male subjects" (1998, p. 15). Whereas much of the ontological, epistemological, and methodological assumptions are similar to the interpretive/constructivist paradigm, the emancipatory paradigm highlights the influence of value-laden views of society, politics, gender ethnicity, and other potentially oppressive structures and policies.

The assumptions made by the researcher in the present study, along with the questions being asked, fall clearly into the interpretive/constructivist paradigm. Data collection strategies involve natural, social contexts and interactions with participants who "actively perceive and make sense of the world around them, have the capacity to abstract from their experience, ascribe meaning to their behaviour and the world around them, and are affected by those meanings" (Palys, 1997, p. 16). As a discourse analyst within this paradigm, the researcher is "interested in language and texts and sites in which social meanings are created and reproduced" (Tonkiss, 1998, p. 246), and uses "a common set of tools to examine how different discourses present their versions of the social world" (p. 249). Moreover, she is keenly aware of the observation made by Hitchcock and Hughes (1995) that "data does not speak for itself but only through the interpreter" (p. 324).

### 1.8.7 Situating the present study

As noted in section 1.3, this study adopts the perspective on language shared by those working in systemic functional linguistics, and uses discourse analysis and concordancing techniques. The researcher describes this study as a qualitative (interpretive/constructivist) multiple case study design using the rationale that each case is a particular group defined by specific characteristics which bind that group together making it distinct from other groups, and that the phenomenon under study within that group can be explored by the researcher's involvement with that group as an observer and participant in its natural context (Bassey, 1999; Hitchcock & Hughes, 1995; Merriam, 1988; Mertens, 1998; Palys, 1997; Stake, 1994; Yin, 1994). Each of the four cases in this study is one classroom, an example of one social practice of teaching and learning. These four social practices, or 'cases', can be explored by looking at the discourses which construct them, thereby combining discourse analysis from an SFL perspective and ethnography, as Chapter 3 will describe. The goal of studying these groups is to examine how the participants construct causal explanations, an examination which may reflect some or all of the theories summarized above.

## 1.9 The format of this thesis

Chapter 1 has introduced the topic of this thesis, stated the research questions which guide the investigation, and offered some information about the theories which both inform and influence the research. Chapter 2 will review previous studies which are relevant to the line of argument presented in the current study. Chapter 3 will describe the data collection procedures and the frameworks for the analysis of the data. The next four chapters will provide a detailed description of the four contexts which have been studied. These include two cases at the primary school level, one mainstream science and one ESL science, and two cases at the high school level, one mainstream and one ESL. These chapters include both a qualitative "thick" description of the classroom interactions and a quantitative examination of causal language features which surfaced in interviews with the students in each of these four cases. Finally, Chapter 8 will provide an analysis and discussion of the findings from the four contexts and will offer implications and directions for future work.

## 1.10 Transcribing conventions

The discourse transcriptions in this study have been presented as clearly as possible for the reader, without heavy reliance on symbols. Some clarification may however be useful and is therefore presented below:

| | | |
|---|---|---|
| [text] | interjection by an interlocutor | |
| Speaker 1:<br>Speaker 2: | [<br>[ | overlapped speech |
| *(italics)* | comment on or clarification of the action by the researcher | |
| (xx) | words could not be understood for the transcription | |
| ... | short, somewhat unnatural, pause by the speaker | |
| — | sudden, abrupt change of direction in content or thought; sudden stop | |

# CHAPTER 2: REVIEW OF THE LITERATURE

## 2.0 An overview of the chapter

In the first chapter, it was briefly noted that although causal explanations are a key part of the language of science and of academic discourse in general, little work has been done to explore the development of these in science and language classes. This chapter will continue that line of argument by reviewing literature on causal discourse to establish its importance in learning and education (Section 2.1). This will be followed by a review of science teaching and science language (Section 2.2) and content-based instruction, primarily as it relates to the teaching of language through science and science through language (Section 2.3). Section 2.4 will then discuss the systemic functional perspective on science writing, particularly how its written form has developed historically, how knowledge of this development may help develop students' ability to deal with this written discourse, and how science knowledge is brought into existence in science classrooms. This leads to a summary of the work on grammatical metaphor, a key area of causal discourse (Section 2.5), followed by a discussion of Halliday's two types of patterning and their relation to science teaching (Section 2.6). Section 2.7 presents Novak's concept mapping and its connections to Halliday's two types of patterning, linking concept development to language development. Section 2.8 discusses the key studies which frame the present study and reveal the research which has been attempted regarding the development of causal discourse. Section 2.9 summarizes the chapter and restates the research questions which guide this study.

## 2.1 Reviewing causal discourse and its stake in learning

The first chapter indicated that causal discourse from a teaching or developmental perspective has been treated in a fairly superficial manner. As mentioned in that section, Cronnell (1981) offered a list of cause and effect relations and constructions which he considered useful to teach in order to help readers comprehend text. More recently, Moreno (1997) examined a corpus of English and Spanish business and economics research articles to compare their use of what she referred to as *causal metatext,* lexical items which she lists in the appendix. Flowerdew (1998) examined explicit cause and effect markers in a small corpus of expert and learner written texts and compared them "to ascertain the overuse, underuse and misuse of these markers on both a syntactic and semantic level" (p. 330). Her findings suggested that English as a second language (ESL) students tend to rely on a small set of linguistic devices—most noticeably conjunctions such as *because, since,* and *as,* and adverbs such as *so, therefore,* and *thus*—to construct causal texts. The author also examined texts designed to teach English for academic purposes (EAP) to see how they presented linguistic devices for constructing causal discourse. She found that many of the explicit causal devices used by expert writers were ignored by the EAP textbooks often in favor of the ones which students were overusing. Flowerdew recommended comparing the list of resources that students typically use with what the experts use, and then focusing on teaching the linguistic devices which the students typically underuse or misuse.

This dependency on sentence-level markers of causality, as Mohan (1997) and Mohan and van Naerssen (1997) stated, seems inadequate given the number of studies which have examined the importance of causal structure in the recall of information in narratives. In fact, it has been posited that the findings from these studies suggest that causal relations are a critical part of narrative discourse structure (van den Broek, Linzie, Fletcher, & Marsolek, 2000). Trabasso and Sperry (1985) examined the question of "what makes a statement "important" in a text" (p. 545) and found that a statement's importance was determined by the number of connections it had in the causal network of the story and whether the event was in a causal chain from the beginning of the story to the end. O'Brien and Myers (1987) studied the effects of causal text structure on memory by measuring how long it took to retrieve concepts in the causal connections of narratives. Their findings indicated that the physical position of a concept in the text was not a factor in recall time; the results supported previous work that highlighted the importance of causal connections in narrative writing. Trabasso, Secco, and van den Broek (1984) stated that the extent to which individuals are able to represent in memory the information they hear or read, and draw upon this knowledge later, is dependent on the logical and causal cohesion of the events in the story (see also Trabasso & van den Broek, 1985). Events anchored in a causal chain in the narrative were remembered better than events which had no causes or consequences, attesting to the importance of constructing causal chains in reading comprehension. The authors suggested that in teaching reading, a focus on discovering cause and effect relations would appear to be a useful skill to develop. Moreover, the authors recommended that writers should endeavor to make it easy for readers to infer causal relations in their writing. Further research on the connections between reading comprehension/memory and the causal structure of the narratives has been carried out by Fletcher and Bloom (1998), Myers (1988), Trabasso, van den Broek, and Suh (1989), Sanford (1988), van den Broek (1988a, 1988b), and Vonk and Noordman (1988). Playing devil's advocate, Giora (1996) warned that causally connected text is not necessarily coherent and easily comprehended. She cited an example and argued that the text must demonstrate other forms of discourse coherence as well as causal connectedness.

In an attempt to see if writers could make a text easier to comprehend, Linderholm et al. (2000) examined the effect of revisions on the causal structure of easy and difficult reading passages with more-skilled and less-skilled readers at the college level. Quantitative and qualitative findings suggested that by revising difficult texts so that (1) their temporal line was straightforward (rather than when consequences precede their antecedents), (2) the goals of the text were made explicit, and (3) the causal coherence was clarified, readers were better able to learn from the text, as indicated by their ability to recall events and answer comprehension questions correctly. Similar revisions to easier texts, however, were found to be ineffective for the more-skilled readers. Overall, the results of the study suggested that when a text's causal structure is not clear, revisions to clarify it can benefit readers. The study was carried out with history texts, and the authors warned that "repairing the causal structure of a scientific text, for example, may not result in findings similar to the ones reported here" (p. 548).

The importance of causality and causal connectedness in writing surfaces in van den Broek et al. (2000), in which the authors stated that "causality is clearly one of the constraints writers use to produce and connect new ideas to existing narrative text" (p. 718). In this study, the authors examined how writers build on what they have already written to see what kind of causal relations they established as they continued their constructions of the narratives. The findings suggested that writers were constrained to maintain a causal connection as they generated new ideas in the narrative. Moreover, "writers did not simply write *any* action that constituted a causal consequent. Rather, they selected ideas that established a relation of causal necessity, either alone or in conjunction with sufficiency, while largely avoiding sufficiency alone" (p. 714, emphasis in original). The causal continuations which the writers offered were most often linked to the last event in the story's causal chain, no matter where that event was located temporally or physically in the story.

This section has revealed three main points which impact strongly on the present research. The first is that regarding the explicit teaching of causal discourse, there appears to have been an emphasis on sentence-level or lexical markers, and there has been little if any discussion of the combination of resources which construct causal text as a whole. The second point concerns the high level of emphasis which the literature has placed on causality and the textual structure of causality in spite of the lack of work on their linguistic resources for construction. It appears evident that causal connectedness in text affects comprehension—and consequently the potential learning—of texts. The third point is that although there has been some research on causal discourse in business and economics texts, some on causal revisions in history texts, and a relatively large amount on the causal structure of narratives and how causal connectedness relates to comprehension, memory, and learning, there has been very little work on the causal structure of science texts, beyond what will be presented in the upcoming sections.

## 2.2 Science teaching and science language

It was stated in the first chapter that language development in science classes has tended to focus primarily on the teaching of technical terms, yet it has become more recognized that learning to talk science "runs rather deeper than 'simply' learning to articulate the words and phrases of a new speech genre" (Scott, 1998, p. 74). Duran, Dugan, and Weffer (1998) insisted that the acquisition of science vocabulary takes second place to mastering the patterns and linguistic expressions for relating ideas in a variety of semiotic forms in scientific contexts. Research into the 'literacy' aspect of 'science literacy' has been expanded, illuminating the depth of connection between language and science learning. Several studies will be reviewed here. (For a broader review of the last 25 years of language arts and science research, see Yore, Bisanz, and Hand, 2003.)

Lemke (1990) examined the discursive practices of science classrooms. Using transcripts of oral interactions and descriptions of the context in which these interactions occurred, Lemke revealed various activity structure patterns—patterns of dialogue which regularly occur in classrooms, such as triadic dialogue, bids to question, and so on—focusing on the thematic patterns which comprise science discourse. These thematic patterns are constructed from semantic relations: "The thematic pattern of the dialogue is the pattern in which these [semantic] relationships are joined together" (p. 14). Lemke stated that it is the patterning of these semantic relationships which define science, and that frequently difficulties in understanding the content stem from differences in the semantic relationships held by the various individuals in the class rather than by the words themselves:

> In fact, the same scientific ideas can be expressed in many different ways, because the semantics of a language always allows us to use grammar and vocabulary in different ways to express the same meaning. The wording of a scientific argument may change from one book to the next, one teacher to the next, even one day to the next in the same classroom. But the semantic pattern, the pattern of relationships of meanings, always stays the same: That pattern *is* the scientific content of what we say or write. (p. x)

The role of science educators, Lemke argued, is to apprentice students into the use of new thematic patterns, or new ways of meaning. This combination of meaning patterns and language was brought up again more recently by Roth (1998), who noted that concepts can be viewed "as the patterns in the language employed by students to describe and explain their science-related experiences, and conceptual change is the change in these descriptions and explanations" (p. 1020). Yet it is often the case that these patterns are left implicit, as Lemke noted, and some students fail to understand the science in them.

Lemke's observation that the same scientific ideas can be expressed in a variety of ways plays a key role in the argument in favor of explicit causal language development in science because, as Carré (1981) noted, the ability to use the scientific register "is positively correlated with the *impression* pupils give of their ability in the subject as assessed by teachers" (p. 11, italics in original). In other words, it appears that the linguistic choices a student makes may play a role in how the teacher views that student's conceptual understanding; a more literate explanation is equated with better conceptual understanding. Yet it appears that science educators in general are often satisfied to make sure that the concepts themselves are understood, and that the various ways of expressing these concepts will develop naturally and unaided alongside this conceptual understanding. Lee and Fradd (1998), for example, advocated having ESL students do hands-on science to facilitate language development, stating that "while students describe and explain their observations in science activities, they acquire the discourse of literacy and the language of science" (p. 18). Buck (2000) promoted student collaboration in ESL science classrooms, arguing that "oftentimes, one fourth-grade student could explain any concepts in ways that are more easily understood by another fourth-grade student" (p. 40). Yet this approach seems to be contrary to the many comments made that children's everyday language is not adequate for explaining science concepts (e.g., Ebenezer & Erickson, 1996; Levine & Geldman-Caspar, 1997; Moje, Collazo, Carrillo, & Marx, 2000; Nieswandt, 2001). Moreover, it has been noted that when learning science, students of all ages tend to give surface-level explanations of what they have observed if they do not have a deeper understanding of the topic (Grotzer, 2003). The notion suggested above that the language of science can be picked up during instruction also contradicts earlier views such as Solomon (1986), who in her article on children's explanations observed that "it is left to the students to pick up appropriate ways of explaining by the ostensive example of the teacher. There are always some that fail" (p. 43). Verelas, Pappas, Barry, and O'Neill (2001) believed that explicit teaching and reading of information books do not necessarily result in students picking up scientific understandings, but that teachers "mediate between the texts and the students" (p. 29). Christie (1986) argued that the failure of students to "master the skills, capacities, and knowledge of schooling goes hand and hand with an inability to handle the language structures necessary to make such mastery possible" (p. 239).

Although the register of scientific discourse has been discussed in the science education journals, and several recent articles have listed the characteristics typical of this register which make it problematic for students, such as the use of the passive, technical vocabulary, and nominalization (e.g., Buck, 2000; Carlson, 2000; Simich-Dudgeon & Egbert, 2000), the primary focus from the science education field has revolved around developing children's conceptual understanding using language which is familiar to the students as the basis for constructing new meanings, and two major works in this area will be discussed here (see Ogborn, 1996, for a condensed review of the research in science education). Ogborn, Kress Martins, and McGillicuddy (1996) developed a theoretical framework for examining explanations in science classrooms, based on the assumption that explanations are accounts of "how things are" (p. 7). This framework contained three main propositions: Explanations in science are analogous to stories with protagonists and actions (no matter how abstract and unfamiliar the entities might be); meaning-making in explanations consists of creating differences, constructing entities, transforming knowledge, and putting meaning into matter; and there are variations and styles of explanations to choose from. Explanation, in Ogborn et al., appears to be synonymous with the construction of scientific knowledge. Their framework suggests a regularity view of causality, with a somewhat positivistic view of scientific reality as being "out there," and it is the scientist's—or at least the science educator's—job to describe what occurs, and through that description, explain. The texts they present for examination include the semantic relations presented by Lemke (1990), but the authors do not refer to any of these relations explicitly. Many of their examples of explanations fit a pattern of description (e.g., *X* has the attribute *Y*), and in fact the authors defend the inclusion of description, labeling, and defining by saying that these must be done to build entities which can participate in explanations and are therefore part of those explanations. Ogborn et al. did not examine how the language itself was being developed or taught; their discussion appeared to reflect the earlier mentioned notion that the students' linguistic ability would develop naturally alongside their understanding of the concepts under study. Yet, as previously mentioned, not all students pick up the language of science, and as Carré (1981) noted, "pupils must come to grips with the science register if they are to succeed in the subject" (p. 11).

In a similar look at how students learn science concepts through the language of the classroom, Driver, Leach, Millar, and Scott (1996) first discussed their views about the nature of science and followed this with a presentation of their research, which was undertaken to explore students' ideas about the nature of science. The data were collected through interviews of pairs of students at three age levels (nine, twelve, and sixteen). The probes used in the interviews aimed to uncover, among other things, insights into how these children reasoned and the connections they made between observation and explanation. The authors developed a framework of reasoning which divided the types into three categories: phenomenon-based reasoning, in which "explanation is seen as a redescription of the phenomenon and, as such, it is seen as an unproblematic portrayal of 'how things are'" (p. 114); relation-based reasoning, in which "the explanation is seen as a generalization emerging from the data" (p. 141); and model-based reasoning, in which the explanation is "expressed in terms of a different theoretical system" (p. 115). The authors suggested that the three types may be developmental; the majority of the students in their study fell into the relation-based category, yet many of the younger students used phenomenon-based reasoning, and of the few students who used model-based reasoning, all were from the oldest group.

Driver et al., while raising interesting notions of the use of models in students' explanations and the connections between observable "evidence" and explanation, exhibited a very non-linguistic analysis of explanations. Whereas this might not have posed a major problem, their discussion of the language of observations and explanations in the three reasoning types became somewhat confusing. For example, the authors commented that in relation-based reasoning, features "are described in the same language categories as observations" (p. 115). What do they mean by describe? How do they define "language categories"? In their discussion of model-based reasoning, they stated "explanations in this case... are expressed in a different language from the language of observations; the language used describes the behavior of the theoretical entities posited" (p. 116). The authors' unfortunate use of phrases such as "different language from" and "same language categories" suggest that they have examined characteristics of the discourse which distinguish, for example, explanations from observations, a task which typically represents the linguist's point of view (Cloran, 1999), yet they offered no linguistic analysis to illustrate what they meant.

Although an interest in the use of analogy and metaphor to explain scientific concepts has surfaced (Ogborn, 1996) and the issue of the appropriateness of anthropomorphic language in explanations has been raised (Taber & Watts, 1996; Zohar & Ginossar, 1998), science educators, as stated in chapter one, have not generally paid much attention to the nature or use of causal explanations in their teaching (Lawrence & Pallrand, 2000), and "'explanation' still remains a largely unexplicated notion" (Ogborn, 1996, p. 159). Several authors have advocated the explicit teaching of science language (e.g., Henderson & Wellington, 1998; McGinn & Roth, 1999; McKeon, 2000; O'Toole, 1996; Prophet & Towse, 1999; Ritchie & Tobin, 2001; Yore, Craig, & Maguire, 1998; Zohar & Ginossar, 1998), but causal discourse as a key element of scientific explanations remains relatively unresearched in favor of research on conceptual understanding (see Ogborn, 1996, for a review of the research in this area). The linguistic element has rarely been mentioned. As Leach and Scott (2000) noted, learning science involves learning how scientists explain concepts, and although students are expected to advance their conceptual understanding and to be able to demonstrate it linguistically—Gruenwald and Pollak (1984) insisted that progression to more abstract tasks in science will not occur until a student can use language to express understanding of a concept—causal language development in science classes has not yet been targeted by the science educators as an area deserving explicit attention.

## 2.3 Teaching *content through language* and *language through content*

The first chapter briefly introduced the use of key visuals to make academic content accessible to readers and to serve as an organizer to help students compose academic texts. These key visuals are graphic representations of knowledge structures, and they aim to help develop thinking skills and language (Mohan, 1986; 2001) while helping the student learn content through language. According to Mohan, there are six core knowledge structures—description, sequence, choice, classification, principles, evaluation—which are common to most, if not all, academic content areas at all levels. These six make up the Knowledge Framework, a theoretical framework for analyzing discourse and social practice, based on Halliday's systemic functional grammar and grounded in a language socialization perspective. The Framework is useful for discussing language and content teaching and learning because education itself is a social practice mediated to a great extent through language. What the Knowledge Framework offers teachers, therefore, is a tool for breaking a lesson's activity into pieces which highlight particular thinking skills, or knowledge structures. By focusing on particular knowledge structures in isolation, teachers can help develop students' language ability within that structure as well as help students access the structure of the knowledge being taught. Several reports of successful implementation of the Knowledge Framework have been presented (e.g., Early, 1989, 1990, 1991a, 1991b; Early, Mohan, & Hooper, 1989; Early & Tang, 1991; Tang 1991, 1992, 1997, 2001).

Stemming from the same functional view of language and strongly influenced by Mohan's Knowledge Framework is the Project Framework (Beckett & Slater, in press), a visual planning tool for use in project-based instruction. The Project Framework, which helps make explicit the connections between content, language skills, and thinking skills, was developed and tested in a university-based, second-year academic, content-based language class with a group of Japanese students learning English in a one-year exchange program. The students reported that the Project Framework made the connections between content and language explicit and thereby helped them understand how their self-initiated research projects were promoting language development simultaneously with content learning. Without the framework, these connections were left implicit, and at the high school level, some students expressed dissatisfaction with project work in their ESL classes because they were not convinced of the language development potential (Beckett, 1999).

Cantoni-Harvey (1987) discussed the teaching of science and language, claiming that "students who learn to write science reports accurately and appropriately can apply this ability to other content areas" (p. 167). She advocated hands-on science experimentation for limited English proficient (LEP) students with the rationale that having the visual context would allow them to extract meaning more easily. Students in the higher grades, the author stated, are at a disadvantage because the language becomes much less contextual. If a learner is unable to participate in a bilingual program or get private tutoring in science, the author suggested, it might be necessary "to interrupt her study of science until she becomes able to resume it in a class taught entirely in English" (p. 166) because it would be unreasonable to have students attempt to read scientific texts in English or to have teachers reteach more elementary concepts to LEP students. Cantoni-Harvey's emphasis is on learning strategies and activities to promote language development through the use of the four language skills of reading, writing, listening, and speaking. As the author noted, "the linguistic and cognitive ability he [the student] gains through reading and listening prepare him for advanced academic tasks that require receptive as well as productive skills" (p. 20).

Rupp (1992) also stressed the importance of hands-on discovery learning in science for LEP students because of the context for language support which this teaching approach provides. The author noted that the cognitive abilities of second language learners may be more advanced than their language use suggests and emphasized the importance of dialogues between students and between the teacher and students during these hands-on experiences as an essential part of learning science and science language. Rupp did not provide examples to show how this language learning might occur.

Parkinson (2000) described a theme-based language course for teaching science and technology at a South African university, advocating the teaching of language through science rather than through a general language course. By grounding language teaching in science teaching, the author argued, the needs and interests of science students are addressed. Students become familiar with the genres and literacies associated with science and the register used in the genres while moving forward in content learning.

O'Malley and Chamot (1990; also Chamot & O'Malley, 1992) developed the Cognitive Academic Language Learning Approach (CALLA), an instructional model which is not intended to duplicate the mainstream curriculum, but is designed to prepare ESL students in upper elementary and secondary schools for the vocabulary, structures, and functions of English they will encounter in mainstream classes. Developing academic language skills and learning strategies is the primary focus of CALLA; content appropriate to the grade level is made comprehensible by "providing additional contextual support in the form of demonstrations, visuals, and hands-on experiences, and by teaching students how to apply learning strategies to understand and remember the content presented" (p. 194). Academic language, the authors claimed, is particularly difficult because it is context reduced and cognitively complex, and because science is taught using a discovery approach with context-embedded, hands-on activities, the authors recommended it as the best content area to begin with. O'Malley and Chamot made no reference to the difficulties of science language which others have noted, but suggested that the move from context-embedded language to the context-reduced form would be done "through a whole language approach in which all language skills are applied and integrated for all areas of the curriculum" (p. 196).

It would appear that content-based language programs are useful bridges to mainstream classes. Kasper (1997) provided quantitative support for the use of content-based ESL instruction as a way to ease students' successful transition to mainstream classes at the college level. The study involved 152 students of which 73 were in the experimental group. The findings suggested that the experimental group generally did better academically than the control group, leading Kasper to conclude that content-based ESL courses "provide ESL students with the linguistic and academic tools they need to succeed in the mainstream college curricula" (p. 318). Gaffield-Vile (1996) also recommended sheltered content courses because they motivated ESL students more and introduced them to the academic culture of English-speaking cultures through the types of assignments they contained.

Many of the authors of content-based instruction in ESL science appear to target the teaching of science vocabulary as the main need. For example, Straw, Sadowy, and Baardman (1997) stated that although students require social language to function in school, the development of "subject-specific vocabularies" is critical "to make students contributing members of the school and academic community" (p. 39). This is echoed in the research questions which guided Carroll and Gallard (1993) in their inquiry into whether students were learning to mimic teachers' scientific vocabulary or whether there was real understanding of the concepts being taught. Vocabulary as a key issue for learners is also clearly highlighted in the British Columbia Ministry of Education's 1999 *ESL learners: A* *guide for teachers.* This document advised teachers to be conscious of the vocabulary they use and to teach the vocabulary of the subject. It also recommended simplifying sentence structure to facilitate comprehension.

While language through content programs can be useful bridges, academic language development must go beyond simple vocabulary teaching and continue after the students' promotion to the mainstream classes because many of these students need continued support to develop their academic language ability, particularly given the five to seven years that it takes to catch up with their native English speaking peers (Cummins, 1984). Key visuals offer this support by helping make explicit the structure of the knowledge, yet as the first chapter suggested, key visuals can produce a variety of different texts, depending on the linguistic resources the speaker/writer chooses. Mohan (1989, 2001) offered comparisons of classification texts written by skilled and less skilled writers and demonstrated how the two texts reveal "something of the complex, and only partly conscious, discourse decisions a skilled writer makes, and an unskilled writer needs to develop" (2001, p. 119). Key visuals offer a way for students to "communicate about information while learning to shape text" (1989, p. 113), but to become skilled composers of discourse, students need continued development and expansion of the linguistic resources available in the English language. With causal discourse, this involves looking beyond sentence-level features, yet this does not seem to be a major area of research in the content-based language learning literature.

The brief review in this section has aimed to show that although there are a variety of perspectives on content-based instruction in the literature, very few acknowledge the role that the development of causal discourse has in the academic language proficiency which students—both ESL students and those who speak English as a first language—need to succeed in higher-level studies, and several approaches advocate the same inadequate sentence-level focus that has been introduced in earlier sections of this thesis. Although teaching approaches based on the Knowledge Framework (Mohan, 1986) address this issue to some extent, a deeper exploration into the causal language students are currently using and how that language might be developed is much needed.

## 2.4 Science discourse: A systemic functional perspective

Probably the richest source of information on causal discourse in science is Halliday and Martin (1993), which offered a rich description of the language scientists use. Halliday and Martin argued that the language of science—discourse which can be challenging and alienating to both children and adults alike—reflects the evolution of scientific knowledge itself. The authors suggested that "physical scientists led the way in expanding the grammar of the language, as they found it, so as to construct a new form of knowledge" (p. 67). The authors argued that this "new" form of knowledge which is taught in schools replaces common-sense understanding, offering an alternate interpretation of the world. They showed how science organizes knowledge in ways that go beyond the observable and argued that for the scientific register of English to be effective in constructing technical taxonomies, it became characterized by grammatical metaphor and in particular by the changing of clauses into noun phrases. As a nominal group, any happening could be defined, classified, or related causally to other happenings in new clauses. This evolution is schematized in the following manner (p. 66):

**From** *a* happens; so *x* happens
because *a* happens, *x* happens
that *a* happens causes *x* to happen
happening *a* causes happening *x*
**To** happening *a* is the cause of happening *x*

As well as technical taxonomies and grammatical metaphor, Halliday described five further categories of scientific English which can pose problems for readers, suggesting that there are other features which could also be added. Interlocking definitions create difficulties because the terms are often defined by other terms within the same text, and these other terms may also require definition. Special expression can also be problematic, according to Halliday, although examples tend to be more common in mathematics than in science. Science discourse also tends to be lexically dense with syntactic ambiguity and semantic discontinuity. All of these features work together to create the distinctive quality of scientific discourse.

The two main genres in science discourse, according to Halliday and Martin, are *report,* used to construct taxonomies to describe *how* the world is organized, and *explanation,* which explains *why* the world is organized that way. The primary difference in the two genres "is that reports focus on things while explanations focus on processes" (p. 206). In that light, explanations tend to contain more action verbs than reports do, and the actions in explanations "are organized in a logical sequence" (p. 191). Martin referred to these logical sequences as "implication sequences," a term which others following Halliday and Martin have adopted in discussing scientific explanations. Rose (1997, 1998), for example, showed how the sequence of events in written technological and scientific explanations link together with each step representing an effect or outcome of the preceding step, with causality either implicitly or explicitly stated. A similar model of explanation was discussed in Wignell (1998), who suggested that an explanation is a sequence of events linked temporally, causally, or conditionally. The clarity of an explanation is also reflected in the causal resources which the author chooses to construct the implication sequence (e.g., Unsworth, 1999).

Unsworth (2001a) examined written science explanations about coal and sound using three types of analysis: from a genre perspective, by looking at conjunctive relations, and by exploring the use of nominalization. He showed how 'events' are packaged into 'things' and how these things are unpacked into events as the implication sequences, part of the schematic structure of the explanation genre, unfold and technicality is built. He advocated helping students understand how this process is carried out by discussing with them not only how to unpack highly nominalized text but also how to transform the more congruent clauses back into the grammatically metaphoric so that students would be able to construct and deconstruct similar explanations.

Young and Nguyen (2002) compared teacher-talk and textbook discourse on the topic of mirrors in a twelfth-grade physics class, using systemic functional grammar. The authors revealed several differences, including (1) the use by teachers of the first person with material processes in the active voice compared to the passive and third person visible in the written text, (2) more mental processes in the written mode than in spoken, and (3) the teacher's use of explicit statements of cause and effect versus the writer's style of explaining through the description of a process. Young and Nguyen cautioned against generalizing their findings noting that "there are certainly teachers whose style of presentation is much closer to the discourse of the textbook and there may be textbook authors who attempt a more interactive style of presentation" (p. 365).

Schleppegrell (1998) used systemic functional linguistics to analyze science "description" written by grade seven and eight students from ethnically diverse backgrounds. She discovered that the students made a variety of grammatical errors, most often concerned with inflectional endings. They also relied heavily on a small set of verbs for their descriptions and exhibited problems with basic sentence structures. With the exception of *be* and *have,* verbs were frequently in tenses other than the timeless present, connected to the specific context which the students were in, such as in the example "in the picture, they are drinking water" (p. 200). Finally, the thematic choices made by the writers reflected different, sometimes non-scientific themes, such as person or specific rather than generic themes. Schleppegrell concluded by suggesting that a basic understanding of functional grammar can help teachers help students improve their writing in science by making explicit the language features which are characteristic to specific genres and registers. She argued this further in Schleppegrell (2001), stating that "knowing how to make the linguistic choices that realize appropriate texts is an aspect of sociolinguistic competence" (p. 536).

Continuing along a similar line, Schleppegrell (2002) analyzed science lab reports written by one native English speaker and three ESL speakers in an upper division university course in chemical engineering. She found that the lack of linguistic resources available to the ESL students led to texts which were less authoritative with obscure meanings. It was not the grammatical errors that the ESL students made that were responsible for the problems with their texts; the difficulties were frequently in the choices the students made from the interpersonal and textual metafunctions, including the grammatical metaphor involved in the construction of logically progressing discourse. The author concluded that ESL writers rely heavily on resources to construct ideational meaning without realizing the impact that their interpersonal and textual choices have on their writing, and that assistance needs to be provided to help these students learn how their grammatical and lexical choices construct meaning in science.

Deconstructing causal discourse into predictable words and patterns has been criticized by some authors such as Watkins (1999), who claims it risks advocating a rigid formula for recreating science genres. Along a similar line, Sawyer and Watson (1995) presented three arguments against adopting a genre approach to teaching science writing. The first challenged the idea that science discourse constructs science meaning, stating that it is instead "a continuum of registers and styles which does not include the scientific *content* as a variable" (p. 69, italics in original). Secondly, the authors argued that the type of science language described by Halliday and Martin is not suitable for school texts; rewriting the texts is necessary rather than "inducting pupils into the linguistic features of expert-to-expert scientific prose" (p. 70). Thirdly, they questioned the model of learning theory that the genre school adopts, asserting that a genre approach to teaching science equals "the rejection of a constructivist view of learning and that... the ideology of the genre school is firmly within a Transmission model long ago discredited as an effective model for learning" (p. 75).

Sawyer and Watson's view regarding the lack of constructivist learning and teaching was based strongly on work done in 1976 by Douglas Barnes, which was cited heavily in their argument. The more recent literature which they cited takes a somewhat kinder view concerning the connections between science language and science content. Still, the authors maintained a critical stance against the genre approach to teaching science, omitting reference to how teachers use constructivist ideas to bridge students' existing language features and understandings to those held by the field of science, and instead insisting that the features which Halliday and Martin and the genre school describe are "*not* necessary to the conveying of scientific knowledge or modes of thought" (p. 71, italics in original).

Despite arguments that science knowledge can be *conveyed*—note the idea of transmission rather than construction which Sawyer and Watson used in the above quote—without the language which Halliday and others have described as characteristic of the field, it is nonetheless important for teachers to consider these linguistic features because, as Derewianka (1990) stated, "if children have an explicit knowledge of what language resources are available, they are in a better position to make informed choices when developing texts of their own" (p. 5). Yet by looking at the views of both the "genre school" and authors such as Sawyer and Watson, it becomes apparent that both students and teachers need to be aware that simply presenting the resources in a grammatically correct manner does not result in the construction of literate scientifically sound discourse, a point which Halliday emphasized:

> Whenever we interpret a text as 'scientific English', we are responding to clusters of features.... But it is the combined effect of a number of such related features, and the relations they contract throughout the text as a whole, rather than the obligatory presence of any particular ones, that tell us that what is being constructed is the discourse of science. (Halliday & Martin, 1993, p. 56)

From the combined perspectives, therefore, when teaching science, language and content should not—cannot—be dichotomized into either a focus on language forms or a focus on science content. Instead, teachers and learners must work together to construct appropriate scientific meanings, introducing and using language features which are appropriate for the students' level of development, and constructing these meanings through their linguistic interactions in the classroom. In other words, developing students' ability to construct causal meanings in science involves much more than simply offering students a list of characteristic lexical items and grammatical structures; although these resources are indeed important, teaching students to read and write academic text involves socializing students into new ways of looking at the world and new ways of linguistically constructing causal relations. The ability to handle grammatical metaphor plays an important role in these constructions.

### 2.5 Causal explanations and grammatical metaphor

In the first chapter, the term *grammatical metaphor* was introduced and defined as being similar to lexical metaphor in that both involve linguistic transformations, but "instead of being a substitution of one *word* for another,... it is a substitution of one grammatical class, or one grammatical structure, by another" (Halliday & Martin, p. 79, italics in original). Whereas in lexical metaphor there is a literal meaning which is different from the metaphorical term(s), with grammatical metaphor, the non-metaphorical construction is referred to as being the more *congruent* form (Halliday, 1994). Considered by Derewianka (1995) to be a vastly undertheorized notion, grammatical metaphor is poorly handled in discussions of academic language development. Typically its only representation is nominalization, which is not surprising given that it has been common to treat grammatical metaphor and nominalization as interchangeable (Derewianka, 1995). Nominalization is frequently defined as a characteristic of written language, often used in school textbooks "to achieve economy of expression" (Crowhurst, 1994, p. 33). A summary of the arguments in favor of and against the use of nominalization is offered in Perera (1984).

Yet nominalization is only one type of grammatical metaphor (Eggins, 1994). In a longitudinal study of her English-speaking son from age five to fourteen, Derewianka (1995) documented the development of various kinds of grammatical metaphor. Her study offered empirical evidence for the suggestion that adult language and child language differed primarily in the use of grammatical metaphor and showed how different types of metaphor emerged at different times, with a dramatic increase in use at around nine or ten years old. Her findings support Halliday's observation that "students well into secondary school may still find it difficult to comprehend, even if they have been educated throughout in the English medium" (Halliday & Martin, 1993, p. 82).

With regards to the shift from the more congruent clause constructions to the more grammatically metaphoric, Painter (1999) discussed the development of causal relations in her son, Stephen, from age two-and-a-half to five years. Interestingly in light of Halliday's observation above, she found that initial expressions of reason involved the hypotactic linking of two processes, and the last to occur were "metaphorical within-clause expressions" (p. 312).

Both Painter and Derewianka also noted that their data revealed the social nature of language learning as they modeled the use of grammatical metaphor for their sons. In Derewianka's recommendations for further study, she advised exploring teacher intervention which might facilitate the development of grammatical metaphor. Mohan and Beckett (2001) responded to this by discussing recasts in causal explanations. Using examples from interactions in a project-based language and content classroom, the authors argued that the teacher's recasts, by using grammatical metaphor, were able to model a more literate way of meaning by turning the students' more congruent forms into ones which were less congruent. The students were not initially able to understand the recasts, but the teacher had created a "zone of negotiation" (p. 151) in which language development could occur. The students' rephrasing of the teacher's recasts revealed the successful development of less congruent language.

## 2.6 Grammatical metaphor and Halliday's two types of patterning

Halliday (1998) argued that grammatical metaphor, in particular nominalization, plays a powerful role in making meaning in science. It "creates a universe of things, bounded, stable and determinate; and... of relations between the things" (p. 228). In other words, these "things" can be technicalized (renamed and reclassified), and processes can be used to relate the "things" in reasoned arguments.[1] Learning science involves these two types of patterning: creating new technical taxonomies, which differ from everyday understandings, and then relating the participants in the taxonomies to each other and to other classifications.

Wignell, Martin, and Eggins (1993) defined the process of technicalizing as involving two steps: renaming everyday terms and reclassifying them into scientific taxonomies. This is done using grammatical resources such as projection and elaboration. For example, a technical term can be introduced by a projecting naming process such as *we say that X* or *we call this Y,* or by an elaboration through an identifying relational clause such as *X is defined by Y.* The authors stated that technicality "refers to the use of terms or expressions... with a specialized field-specific meaning" (p. 144) and that "different fields will name, reorder, or reclassify similar things differently according to what is 'emic' (meaningful or relevant) to that field" (p. 139). Teaching the field of science from this perspective, therefore, involves renaming and reclassifying everyday things to create new technical taxonomies.

Carroll and Gallard (1993) argued that the introduction of new technical terms promotes new learning. They stated that if the teacher talks about a scientific event using terms from

1. Hartnett (2001) presented several factors involved in the use of nominalization, including the use of previous knowledge to build new knowledge, rhetorical organization, inclusiveness, and efficiency. She also stated that nominalization use changes as language changes, and that this use may be on the decline.

the students' everyday vocabulary, the students are already familiar with the concept and therefore no negotiation of meaning is required and no new meaning-making occurs.

Halliday (1998) showed how the resources of the grammar are used to build sequences of reasoned arguments and the role grammatical metaphor plays in that process. In constructing arguments, the author stated, the grammar construes both experience, through the ideational meaning, and the grammar itself, by creating a cohesive and coherent piece of discourse. He described "the 'general drift' of grammatical metaphor" (p. 211), which sees movement from relator (conjunctions) to circumstance (adverbial phrases) to process (verbs) to quality (adjectives) to entity (nouns).

Halliday's two types of patterning offer a way to look systematically at the teaching of science language and content. Classroom interactions can be examined to see how teachers are creating technicality and modeling new, more literate ways of arguing. Analyzing the discourse from this perspective can also help researchers and educators see the language resources students are using to construct causal explanations in science and may perhaps be exploited to judge to some extent how satisfactory these explanations are for their grade level.

## 2.7 Mapping the development of concepts and language

Novak has for several years used concept maps to investigate concept learning. In his 1998 book, he offered concept maps drawn from interviews with a boy named Paul about his understanding of matter, done in both grade two and grade twelve. In Paul's earlier interview, the concepts which appeared in his map numbered twenty, with only one technical term ("oxygen") included. By grade twelve, there were fifty-one concepts, of which more than half were either technical or metaphorical terms. Novak noted that the later effort showed both "quantitative and qualitative growth in Paul's conceptual/ propositional knowledge about forms of matter" (p. 67). Novak (1988) provided a similar example using two maps of matter drawn by a student named Phil in grades two and twelve.

Given the notion that "conceptual change is an ongoing process in which the child, in collaboration with a teacher or other student, integrates everyday concepts into a coherent system of concepts" (Howe, 1996), several authors have also examined the use of concept mapping to reveal concept learning. Harrison, Grayson, and Treagust (1999) noted that the participant in their case study, Ken, had increased the number of entries and connections on his concept map by the end of forty periods of studying heat and temperature. The authors attributed this increase to Ken's greater understanding of the topic. Jones, Carter, and Rua (2000) presented concept maps drawn by their participant, Cary, to show the differences between the grade five student's understanding of heat and convection before and after being taught the topic. The authors also presented a scientist's concept map of the same topic which contained only nineteen concepts. They argued that the number of concepts may in fact be lower in maps drawn by specialists in the field than by learners.

The lower number of concepts in specialist maps can be explained easily by considering Novak's (1998) explanation of representational learning. The author stated that

> once a child learns that all dogs have certain common characteristics, he or she has acquired the concept *dog*. Similarly, children may recognize similarities between dogs, cats, lions, and tigers long before they learn the word *carnivore* to label or represent this group of flesh-eating animals. (p. 37)

A specialist may include a word like *carnivore,* whereas non-specialists may not have this term in their linguistic resources and may instead include examples of the class word. What is therefore important to note about this type of technical term when considering the concepts which exist in a particular map is that the word itself may be constructing more than a simple one-to-one representational meaning. Hence, the number of terms presented in a concept map may be fewer in one created by a specialist in the field, but the meanings which the terms incorporate create a much larger network of ideas. Pollak (1994) captured this idea when he stated that as science matures,

> its conceptual structure becomes more efficient, and is capable of accommodating vastly more information… it is no longer necessary to remember vast amounts of detailed information. In fact, a fundamental goal in the development of models and theories is inclusiveness—to account for more and more on the basis of the fewest and simplest fundamental ideas.… By virtue of greater sophistication, as a science matures things become simpler, not more complex. (p. 96)

Indeed, the differences between the preconcept and postconcept maps in the Jones et al. study revolved around the types of concepts included. Whereas the preconcept map included few technical terms or metaphoric entities, the postconcept map contained several. The number of everyday concepts dropped in the latter. In the scientist's concept map, there were no everyday terms; the concepts captured technical terms, laws, theories, and nominalizations of processes, each of which involve knowledge which goes beyond the simple representational connections between observable ideas or things and their labels, yet the scientist obviously felt no need to include this knowledge because he already had a technical or metaphorical term that captured the knowledge which had already been constructed. It is this type of difference which seems to play a key role in capturing the development of conceptual knowledge in the concept maps.

Aside from the numbers and types of terms included in the concept map, another difference can be found in the relations or propositions which were constructed around and amongst the concepts. Novak (1998) constructed Paul's grade two map using connections such as *is made of, as in, is, into, by, can,* and *when.* Paul's grade twelve map, in comparison, included such language as *is made of,* but also *makes up, causes, produces, aids, comes from, means,* and *forms.* In other words, more causal relations were evident in the more mature concept map. A similar pattern emerges when the three maps in the article by Jones et al. (2000) are examined. The preconcept map in their study contained relational processes such as *is, gets, turns,* and *has,* as well as circumstances such as *in oven* and *into the air.* The postconcept map added to the variety of relational process with *involves* and *is called,* but also included more causal processes and circumstances of cause, such as *can be made by.* The scientist's map included not only causal processes, but processes of evidence and metaphorical constructions: *causes, explains, leads to, is due to, depends on, involves, drives, is measured in,* and *is the source of.*

It could be suggested, then, that the scientist's concept map includes (1) a much higher level of technicality, with abstractions such as theories and models, and nominalizations representing and containing more detailed but invisible conceptual structures, as well as (2) more causal and metaphoric ways of reasoning among them. This finding, as suggested by examining the concept maps presented in papers such as Novak (1988, 1998) and Jones et al. (2000), parallels Halliday's two types of patterning, revealing how the development of science concepts and science language appear to go hand in hand. But how has the development of causal explanations—which involve these two types of patterning—been researched from a linguistic perspective? The next section will review the key studies which have been carried out regarding the development of causal explanations in school science.

## 2.8 The development of causal explanations in school science

The development of causal explanations has been explored, although not in adequate depth, both from the classroom level, where teachers interact with students to deepen their understanding of the topic, and from the curricular perspective, through texts written at various levels by experts. This section will review the available literature of both areas.

### 2.8.1 The development of causal explanations in the classroom

Haneda (2000) explored the interactions between a teacher and two grade three Chinese-Canadian students as they conducted and discussed an experiment on refraction. The author was particularly interested in examining how the students participated in the interactions, and in the connections between the talk and the students' subsequent writing task. Haneda noticed differences between the two students with regards to their involvement with the topic in both the interaction and writing tasks, with the girl—Jasmin—using different types of talk as the interactions progressed from a recount to an explanation attempt. The author further noted that talk which was concerned with procedure saw the children taking the lead, but when the task shifted to explanation, the teacher scaffolded the students' understanding so that Jasmin could begin to reason logically about the topic. Alex, the boy in the study, remained at the level of doing and observing, with the author inferring that the interactions were beyond what Vygotsky termed the zone of proximal development (Vygotsky, 1978). Haneda concluded that although it was evident that interactions between teachers and students can help students learn, more research should be undertaken, particularly with regards to probing how these interactions can promote deeper thinking.

Gibbons (1998) examined the language development of nine- and ten-year-old ESL students learning about magnetism by following the progression from the hands-on activities which Veel (1997) stated begins an investigation of a topic, through to the students' written reflection on their learning. She addressed this development from a register perspective, describing in detail the moves which occur in the classroom during three stages: the hands-on activity of lab experiments, the teacher's scaffolding of decontextualized recounts of the labs, and the more generalized written discourse. She focused on the move between these stages, highlighting the way the language shifts from the interpersonal to the ideational, and elucidating the role that the teacher plays in helping students adopt the more academic registers of science.

Gibbons offered a valuable description of the natural teaching progression from experimentation to teacher-guided oral discussion to writing, discussing the use of the teacher's recasts and encouragements in helping the students appropriate the new science-specific lexis and a more decontextualized way of talking. She argued in favor of having the students come to some understanding of the topic through hands-on activities before introducing and reinforcing the new science language, yet there is no comparative data to see what the discourse might look like if the new terms (e.g., *repel)* are presented before the students become engaged in the action. Is it the order of presentation or the teacher's strategies for connecting experience to language that becomes important in the teaching? Are there more strategies than the recasts and encouragements the author mentioned? As Gibbons stated, more classroom-based research into how students learn language in school is needed.

In Gibbons (2003), the author provided deeper insights into the strategies her teachers used to bridge the students' experiences and everyday language to a register appropriate for school science. Slightly different from her 1998 article, her research participants in this paper were eight- and nine-year-old mostly ESL students and their teachers who were trained ESL instructors teaching language and content simultaneously. Although the author framed the study along a mode continuum from the oral, context-dependent language of group work to the written, highly context-independent discourse of a science encyclopedia written for youths, this article focused on the stage she referred to as "teacher-guided reporting" (p. 256), in which the bridging of students' existing understandings and abilities and the new target knowledge occurred. Gibbons discussed four key ways the teacher used to mediate language learning (p. 257):

1) mode shifting through recasting,
2) signaling to learners how to reformulate,
3) indicating the need for reformulation, and
4) recontextualizing personal knowledge.

These four ways were supported with discourse examples analyzed to reveal the moves the teachers were making. Particularly interesting was the example of mode-shifting, in which the teacher's discourse was divided into columns indicating "situationally embedded," "everyday," and "formal," making it easy to see how the teacher was drawing parallels between the students' current linguistic forms and the target school language.

Gibbons concluded her paper by stating that her examples were not unusual and that "similar interactions between teachers and students probably occur daily throughout hundreds of classrooms without teachers being explicitly aware of the nature of their responses" (p. 268). Her data, however, were limited to two trained ESL teachers working in two mainstream classes heavily populated with ESL students and containing eight- and nine-year-old children. Would teachers without specific language training use the same strategies to teach science content and language? Would the same strategies be used at different age levels? Further qualitative research needs to be carried out in different contexts, both ESL and non-ESL and with younger and older students, to paint a more complete pictures of what the interactions in classrooms look like and how they promote—or even fail to promote—language and content learning.

### 2.8.2 The development of causal explanations across grade levels

Veel (1997) noted that the school curriculum reflects a progression similar to the evolution of science language, from the more observable, sequential treatment of science content to the more abstract, causal language. He claimed that this "idealized knowledge path" (p. 189) mirrors the way that children acquire language. Explanations for younger students tend to be sequential accounts of observable events, and it is only when the student can deal with more abstract or theoretical concepts that the explanations progress beyond the language of sequence. Veel proposed that there are four linguistic indicators which mark the development of content and move students from the younger, sequential explanations towards "the abstract, technical and 'transcendental' kinds of meaning we expect of adult, educated discourse" (p. 188). These four indicators—an increase in lexical density, a higher number of nominalizations and abstractions, a shift from temporal to causal conjunctions and a move from external to internal text organization—were demonstrated in Veel's selection of written genres.

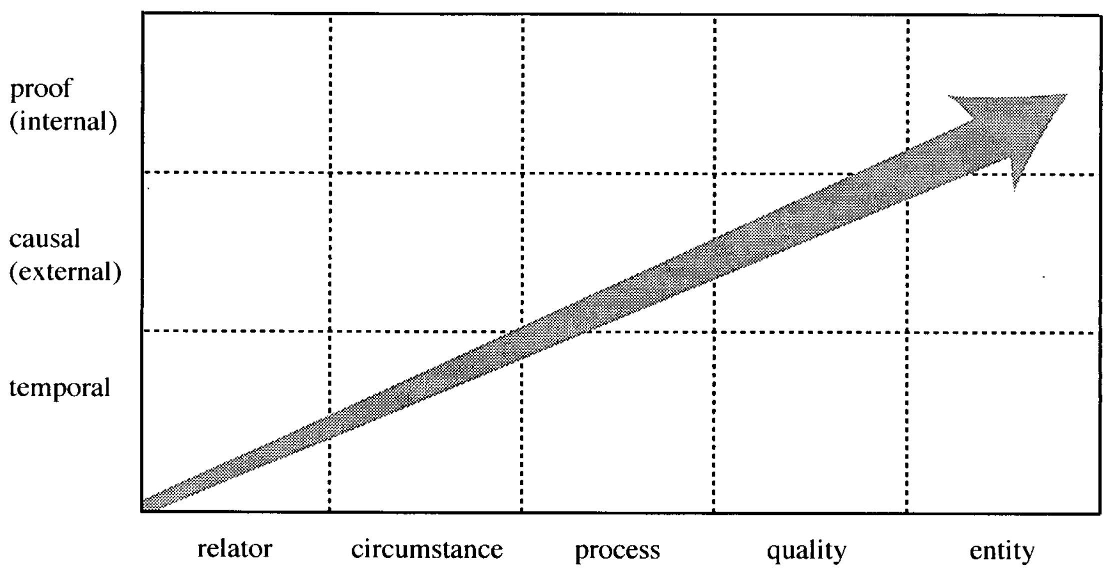
Although Veel makes his claims using only four short texts from four different topics—making sugar, sea breezes, physical weathering, and buoyancy and density—his work is valuable because it provides a clear set of hypotheses which he illustrates well using these four texts. Yet there are difficulties with these hypotheses in that beyond suggesting that there will be an increase in lexical density and nominalizations, Veel focuses on temporal and consequential conjunctions as well as internal and external conjunctions, therefore putting a great emphasis on the role of conjunctions in the development of his knowledge path. His basic hypotheses about these are:

- Temporal conjunctions decrease
- Consequential conjunctions increase
- External conjunctions decrease
- Internal conjunctions increase

Moreover, Veel does not address how the temporal and consequential conjunctions or the external and internal conjunctions are related to lexical density or nominalizations beyond suggesting that "there are recognizable syndromes of language features, and that these features work to produce a kind of knowledge path along which ideal pedagogical subjects will move into fully fledged scientific discourse" (1997, p. 190). Rather than putting such a strong emphasis on logical relations as Veel has done, a closer examination needs to be taken to see the connection between these conjunctions and the move towards grammatical metaphor.

To explore Veel's hypotheses more fully and to elaborate on the role grammatical metaphor may play in the knowledge path, Mohan, Slater, Luo, and Jaipal (2002) used a computer concordancing application combined with hand analysis to examine discourse samples from a science encyclopedia for learners aged eight to fourteen and from one targeted for older, university-level students. The features for analysis were taken from lists of causal items provided by previous concordancing studies (e.g., Fang & Kennedy, 1992; Flowerdew, 1998). To address the issue of the move from conjunctions—or relators as Halliday (1998) terms them—to the more grammatical metaphoric constructions, the authors proposed that there be two axes of development working together, as shown in Figure 2.1. Rather than the knowledge path developing primarily along the temporal/causal axis through conjunctions with entities (nominalizations and abstractions) situated outside of this axis as Veel has described, Mohan et al. offered a schematized developmental path which moves out from the lower left corner at a roughly 45-degree angle. This model suggests, as does Veel, that there is a shift from temporal conjunctions towards ones which signify causality and proof at the same time that there is a shift from external to internal conjunctions. But the model goes beyond Veel's idea to suggest that there is also a move away from conjunctions as the primary marker of causality towards the more grammatically metaphoric constructions such as circumstances, processes, qualities, and entities. The order of these more metaphoric categories stem from Halliday (1998), who described this progression as "the 'general drift' of grammatical metaphor" (p. 211), from the clause complex, through to clause, and finally to nominal group, the most metaphoric construction.

**Figure 2.1: Idealized developmental path for cause (Mohan et al., 2002)**



When Mohan et al. tallied their findings from the corpus analysis and held them up against Veel's hypothesis and their own idealized developmental path, they found that there was a tendency for the encyclopedia written for the younger group to have more temporal external conjunctions than the discourse constructed for older readers, confirming Veel's hypothesis that temporal conjunctions decrease. Contrary to Veel's findings, however, external consequential conjunctions also decreased. With regards to the shift from external conjunctions to internal ones, when only temporal and causal conjunctions were considered, there was a move, as Veel had hypothesized. However, when the total number of internal conjunctions were brought into the picture (i.e., temporal, consequential, additive, and comparative, as Veel outlined on p. 186), there appeared to be no difference between the encyclopedias written for younger and older audiences, thereby refuting Veel's hypothesis.

Mohan et al. went on to track the frequencies of various processes, qualities, and entities in the two corpora as well. What they discovered was that whereas the numbers of causal processes dipped slightly in the encyclopedia for older students, the number of proof processes increased, suggesting a more metaphoric move through processes from external to internal. Moreover, the frequencies of causal qualities and causal entities also rose. It should be noticed, however, that not all categories of causal features were examined by Mohan et al. Temporal processes, qualities, and entities, and all circumstances as well as the proof qualities and entities were not reported. Furthermore, only items which had been listed in the previous concordancing literature were counted even though there were potentially other items existing in the data. Despite this, though, their findings appear to suggest that between these two encyclopedias there is a move from the use of conjunctions to more metaphoric ways of constructing meaning. In general, the findings from their corpus study suggest that the developmental path between temporal and consequential conjunctions does not work out as Veel had hypothesized, but that a path can work if Halliday's "general drift" toward grammatical metaphor is built into the theory, focusing on time/cause relations.

Veel (1997) and Mohan et al. (2002) have attempted to show developmental moves at the curricular level of school science, but in his chapter, Veel inferred that this knowledge path is also noticeable at the level of the teaching unit. He stated:

> The investigation of a topic in the classroom, for example, will frequently commence with physical activities such as experiments and observations, proceed to more generalized 'bookish' study of the topic and conclude with an investigation of how the topic in question affects people's lives. In terms of written genres, this will involve a shift from procedures and procedural recounts to explanations and reports and then to expositions and discussions. (p. 174)

Veel's observations about genres and classroom investigations are also captured in Unsworth (2000, p. 249; 2001b, p. 125), who charted the progression of the principal genres involved in "doing science," "explaining events scientifically," "organizing scientific information," and "challenging science." Unsworth further noted that oral language typically uses conjunctions to construct logical relations whereas in writing, the same meanings are constructed using nouns and verbs. His observations, which were supported with examples in Unsworth (1999, 2001b), were concerned with a mode continuum from oral to writing, and the register shift which accompanies this shift. Is there a difference in the use of conjunctions versus the more metaphoric features within the oral mode as the understanding of field deepens? Unsworth's work, while valuable in showing the general and distinctive differences between spoken and written science discourse, did not examine how or if the language changes as understanding of the field grows, even when the mode remains constant.

Section 2.8 has discussed the literature which impacts strongly on the current research project. Veel (1997) and Mohan et al. (2002) examined the development of causal discourse over the school science curriculum. Both studies served to highlight the observation made in Derewianka (1995) that the development of grammatical metaphor is critical to success in secondary school. But both studies were concerned solely with texts written by experts. Unsworth (1999, 2001b) described the differences between oral and written science discourse, but was concerned with native English speakers/writers and did not address the development of academic register within the oral mode alone (or even within the written mode). Haneda (2000) detailed the development of two students learning through interactions with the teacher, but her study raised questions as to why one student benefited from the interactions while another didn't, and how interactions might help all students understand. Gibbons (1998, 2003) presented discourse evidence to show the role her ESL teachers played in helping the students learn more academically appropriate registers, but her research focused on eight- to ten-year-old students taught by ESL language and content specialists. How do other teachers teach science language and content to other groups? How do the students in other classes talk science after studying the topic under investigation? How does the use of oral language features compare with that of the written features described by Veel or Mohan et al.? How does the use of oral language features compare between ESL and non-ESL students at different ages? Do different teachers use similar interaction strategies? These few studies raise many research questions, some of which the current study aims to respond to.

## 2.9 Summary

This chapter has reviewed several areas of the literature which are relevant to this research. From the review above, it was revealed that except for the work of those in the area of systemic functional linguistics, the treatment of causal discourse has generally been centered on sentence-level lexical markers. Furthermore, although causal connectedness has been acknowledged as playing a critical role in text comprehension and learning, very little research has to date examined the development of this connectedness or explored how students learning the language of cause and effect in science classes construct their texts. Moreover, from a teaching perspective, a review of the literature from the science educators has suggested that the explicit development of causal discourse in science classes is not a focus for instruction, so it would seem that students must be acquiring it implicitly. Yet how implicit is this causal language teaching in mainstream classes? Is it more or less explicit in content-based language classes? The literature has suggested that in content-based language classes, there has been an effort to develop students' language ability through content teaching, particularly in classes which use Mohan's Knowledge Framework. Based on the literature, however, much of the explicit language teaching has been limited to sentence-level linguistic devices which help students reach a level where they can move into mainstream classes, but does not necessarily help them reach the same level of academic literacy that their native English-speaking peers are at. To reach this level of literacy, students need to develop their ability to handle grammatical metaphor, a linguistic ability which research on native English-speaking individuals has shown distinguishes adults from children (Derewianka, 1995), but which has had very limited research from the second language acquisition field. How is grammatical metaphor being developed in ESL science classes and in mainstream science classes? How are the participants in these classes constructing causal explanations? Are causal explanations constructed by ESL students qualitatively different from those constructed by non-ESL students?

The current study uses concordancing techniques and discourse analysis to examine how the participants in four different contexts develop causal explanations and the taxonomies from which the explanations draw, and what the language features are which the students use. The four contexts reflected different populations (ESL and non-ESL speakers) and different age groups (six to eight years old and fourteen to sixteen years old). The questions which guide this examination within and across the four contexts are as follows:

1. How do the teachers and students develop causal explanations and their relevant taxonomies through classroom interactions?
2. What are the causal discourse features which the students in the four contexts use to construct causal explanations?

This study aims to add to the current knowledge base of how causal explanations are constructed by examining the development of field through an analysis of the social practice of teaching science, and by employing corpus linguistics to reveal potential patterns in the development of causal explanations. This study should also open up a new area of research through its examination of ESL speakers' development of grammatical metaphor in causal explanations at both the classroom and the curriculum level.

# CHAPTER 3: METHODS OF INQUIRY

## 3.0 An overview of the chapter

This chapter is concerned with the methodology of the study. The first main section presents the research design and discusses the various theories and methods which have informed the study. In Section 3.2, the main research procedures are described, including the sampling considerations, the research sites, and the participants. Section 3.3 talks about the role of the researcher. In Section 3.4, the three types of data—observations, interviews, and documents—are discussed, followed in Section 3.5 by illustrations of how the data are presented. Section 3.6 discusses the trustworthiness of the research design, and Section 3.7 offers a summary of the chapter.

## 3.1 Research design

The questions which form the investigative purpose of the research help determine the design of the research or the approach the researcher will take (Knobel & Lankshear, 1999; McMillan & Schumacher, 1993). In this study, the questions dictate an analysis of the interactions between teachers and students which are concerned with causal explanations. Before the discourse can be analyzed, however, it needs to be collected, and as the act of explaining is a natural social activity occurring within the contexts of science classes and during conversations about science knowledge, it is expected that naturalistic inquiry carried out in such contexts would offer a wealth of relevant explanation texts. Such naturalistic inquiry is what lies at the heart of interpretative/constructive research.

### 3.1.1 Interpretive/constructivist (qualitative) research

As discussed in Section 1.8.6, the purpose of qualitative research is to clarify an area of inquiry that is currently unclear by describing, interpreting, or explaining—using verbal language as opposed to the mathematics of positivist/postpositivist (quantitative) designs—the social actions within the context under investigation; in the qualitative part of this study, these social actions are interactions between teachers and students which serve to construct explanations using the appropriate science taxonomies and logical relations. Because the questions which guided this study required data from four distinct groups, qualitative data collection procedures such as observations and interviews needed to be carried out at several sites. An appropriate qualitative design, therefore, was to investigate several cases, each representing the age levels and backgrounds suggested by the research questions.

### 3.1.2 Case study research

Considered somewhat synonymous to qualitative research by some authors (e.g., McMillan & Schumacher, 1993), case study research means different things to different people (Bassey, 1999; Burton, 2000; Hitchcock & Hughes, 1995). According to Bassey (1999),

> Case study research has no specific methods of data collection or of analysis which are unique to it as a method of enquiry. It is eclectic and in preparing a case study researchers use whatever methods seem to them to be appropriate and practical. (p. 69)

It may be because of this flexibility and adaptability that case studies have become such a popular method of conducting research (Burton, 2000; McMillan & Schumacher, 1993).

Two types of case study designs are available: single case design and multiple case design (Knobel & Lankshear, 1999). In the former, one 'case' in a real-life context becomes the focus of an in-depth study. In multiple case design, several single-cases become the focus, allowing them to be held up for comparison. Spradley (1980) placed these designs within a scope continuum running from a micro-ethnography, in which a single social situation is examined in depth, to a macro-ethnography, which looks at a complex society. Figure 3.1, borrowed from Spradley (1980, p. 30), captures this research scope. The present study utilized a multiple case design—or in Spradley's terms, multiple social situations—using data collected from naturalistic observations of whole-class and small group interactions, interviews with participants, and documents which included instructional materials as well as student-produced work. Discourse and corpus analysis from a systemic functional linguistic perspective were carried out on the texts collected from these contexts.

**Figure 3.1: Spradley's variations in research scope**

| SCOPE OF RESEARCH | SOCIAL UNITS STUDIED |
|---|---|
| Macro-ethnography | Complex society |
| | Multiple communities |
| | A single community study |
| | Multiple social institutions |
| | A single social institution |
| | Multiple social situations |
| Micro-ethnography | A single social situation |

### 3.1.3 Discourse analysis

According to Poynton and Lee (2000), discourse analysis has become an important tool for exploring the increasing complexities of research sites and questions, but they noted that "there is very little literature to support researchers to develop a repertoire of techniques appropriate for their needs" (p. 5). Discourse analysis, the authors claimed, means different things to different researchers and, as Tonkiss (1998) stated, it can therefore be a difficult method to pin down. As mentioned, this study examines the discourse from the perspective of systemic functional linguistics, which views language as a resource from which knowledge is constructed (Halliday, 1994; Halliday & Martin, 1993). This perspective has influenced social practice theory (Mohan, 2003), which will be described in the next section.

When analyzing discourse data, Tonkiss stated, it is typically unnecessary to provide an account of all data collected in the study; on the contrary, "it is often more appropriate and more informative to be selective in relation to the data, extracting those sections which provide the richest source of analytic material" (1998, p. 253). This can be done by examining the data for key words, themes, patterns, and other details deemed relevant to the research questions by the analyst. In this study, texts which appeared to be causal explanations and causal relations were selected for a systemic functional linguistic analysis, using also social practice theory and elements of corpus analysis, topics which will be described in the next two sections.

### 3.1.4 Social practice theory

It was mentioned in Section 3.1.2 that a case study, in Spradley's words, is a single social situation. In Mohan's social practice theory (2003), a single social situation is termed a social practice, a unit which has both a theory and a practice aspect to it. This theory and practice element has parallels with ethnography, sociology, and linguistics, as Figure 3.2 (from Mohan, 2003) reveals. The discussion in this section will focus on social practice theory and its connections to Halliday's systemic functional linguistics.

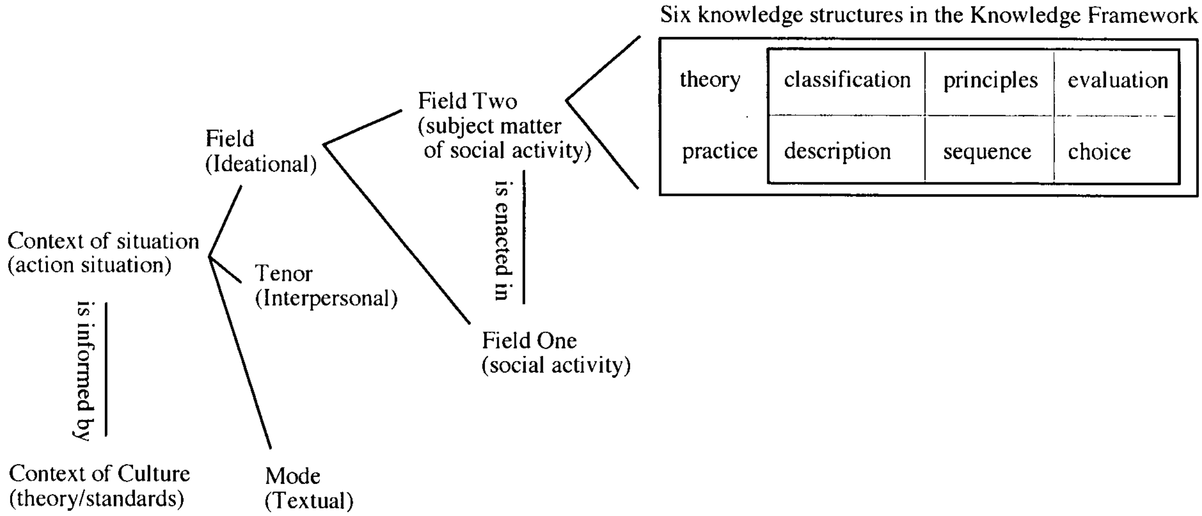
A basic premise of systemic functional linguistics is that language is wholly connected to the context in which it is used. Context, according to this perspective, is interpreted as having two levels: context of culture and context of situation, as the diagram shows. The context of situation refers to the immediate context of language use, whereas the context of culture encompasses "the full range of systems of situational contexts that the culture embodies" (Christie & Unsworth, 2000, p 3). The context of culture informs the context of situation in that its features concern the general standards, rules, or theories of the culture.

**Figure 3.2: Social practice, ethnography, sociology, and functional linguistics**

| **Social Practice**<br>Mohan (2003) | **Ethnography**<br>Spradley (1980) | **Sociology**<br>Goffman (1974) | **Linguistics**<br>Halliday (1999) |
|---|---|---|---|
| Theory | Cultural knowledge | Frame | Context of culture |
| Practice | Cultural behavior | Action strip | Context of situation |

A context of situation is described by examining field (e.g., what is going on), tenor (e.g., who is involved), and mode (e.g., what part language is playing). Field can be further divided into Field One, the "social activity being pursued" (Halliday & Matthiessen, 1999, p. 321), and Field Two, the subject matter which concerns the Field One action. Field Two—which can be described in terms of knowledge structures, abstract categories which "are defined on the basis of logicosemantic relations" (Mohan, 1989, p. 133) and which are reflected in the expository texts of sociocultural situations—is enacted in Field One. Figure 3.3 captures this description. As stated in Chapter 2, knowledge structures move across modal boundaries, and less competent speakers and writers typically have fewer linguistic resources to use in the construction of field than expert speakers and writers. This reasoning in particular makes Mohan's perspective useful in examining differences in linguistic resources which may appear in the interactions of teachers working with learners whose ages vary and with ESL/non-ESL speakers. The current study is concerned in part with these differences.

**Figure 3.3: Contexts and the Knowledge Framework**




As discussed above, the context of culture is concerned with the general theory which informs the action or practice associated with the context of situation. This theory and practice are components of a social practice, as Figure 3.2 outlines. Corresponding to theory and practice are reflection discourse and action discourse, discourse which revolves around the same field, or topic. Reflection discourse parallels Field Two (what is talked about), and action discourse parallels Field One (the activity itself). Mohan (2003) provided a model of social practice to illustrate this at a basic level using the game of Bridge (see Figure 3.4). In Mohan's example, the practice of the game is the hands-on action which captures Halliday's context of situation (paralleling Field One), where the talk is in the context or action of the activity. Reflection discourse, corresponding to Halliday's context of culture and parallel to Field Two, is divided into two types: specific and generic. Specific reflection is a comment

**Figure 3.4: Mohan's model of social practice (basic level)**

| **Social Practice** Mohan (2003) | **Discourse** | **Card Game** | **Example** |
|---|---|---|---|
| Theory | Reflection: generic<br><br>Reflection: specific | Rules<br><br>Advice on play | (1) Rulebook: 'The dealer has the right to make the first bid.'<br>(2) Advisor: 'Say "I bid three clubs"' |
| Practice | Action | Actual play | (3) Dealer: 'I bid three clubs.' |

comment on the actual hands-on action, whereas generic reflection becomes the theory which guides or is drawn from all instances of the hands-on action. In Mohan's Bridge example, the action is the hands-on play of the game, and the generic reflection is the rule or direction which informs the particular hands-on play. Put differently, the generic reflection discourse provides a causal explanation reconstruing what is occurring at the action level: The dealer makes a bid first because he has the right to do so.

This social practice model of Bridge provides a useful template for examining science teaching and learning because a primary goal of science teaching is to help the students understand the "rules" (laws, theories, principles, and so on) of the science topic so that they will be able to provide causal explanations about the topic under study. This can be done by identifying and examining the action and reflection discourse to see whether and how it interacts and constructs the field. Moreover, the social practice model offers an interesting look at learning and teaching in general. Theory, as reflection discourse, is the main offering of discourse-based learning and teaching, such as through textbooks, lectures, and seminars. Practice is played out in the action discourse of experiential learning activities such as labs and fieldwork. As a social practice, the interaction between theory and practice, or reflection and action, when learning and teaching is examined appears to be less straightforward than the interaction between the rules and the play of Bridge. The potentially problematic interaction of theory and practice in the social practice of teaching and learning is illustrated in Figure 3.5 (from Mohan, 2003) and will be examined further in this thesis.

**Figure 3.5: Social practice in learning and teaching (Mohan, 2003)**

| Social practice | Discourse | Learning and teaching |
|---|---|---|
| Theory | Reflection | Expository learning (lectures, textbooks, seminars) |
| Practice | Action | Experiential learning (labs, fieldwork, the world) |

### 3.1.5 Corpus analysis

Biber, Conrad, and Reppen (1998), in their book about corpus linguistics in investigating language, hailed the benefits of this methodology for examining students' use of linguistic resources. The authors stated that "using even a relatively limited corpus... enables substantial gains in our understanding of language development issues" (p. 177). Biber et al. listed the characteristics of this type of analysis as being empirical and using computers extensively to explore, both quantitatively and qualitatively, the patterns of use in large collections of natural texts. McEnery and Wilson (1996) contrasted a corpus with any body of data by stating that the corpus is chosen to represent maximally the language variety being examined, and that a corpus is typically considered to be a standard reference that other researchers have access to. These latter authors cautioned their readers, however, to "be aware of the possibilities for deviation in certain instances from this 'prototypical' definition" (p. 24).

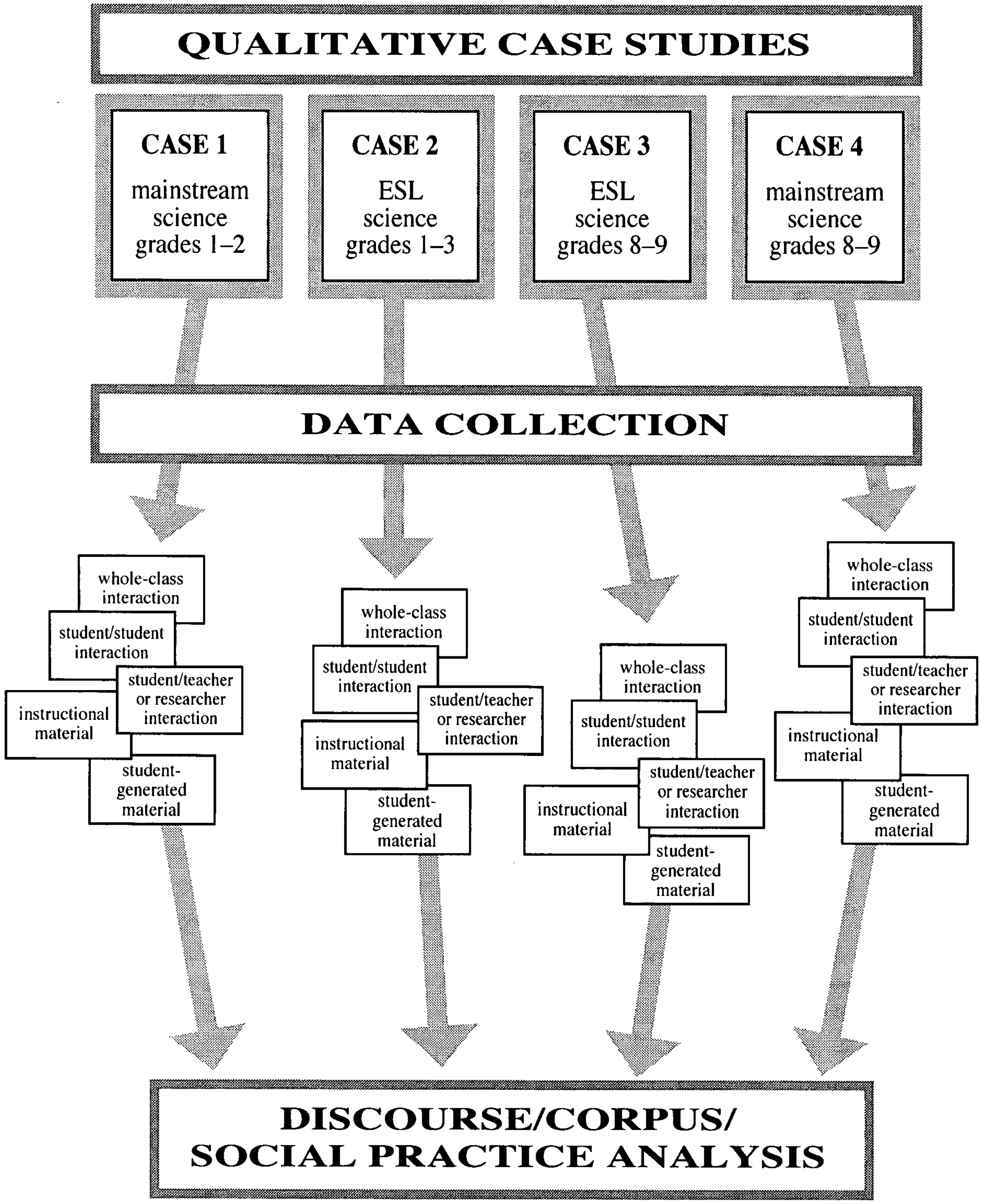
Both the Biber et al. book and the McEnery and Wilson text commented on the lack of available corpora in certain areas. Biber et al. described the limited public resources of spoken and written texts produced by language learners in natural settings and stated that the "corpora produced by older children and students" (p. 175) are even fewer. McEnery and Wilson predicted that "there will be for the foreseeable future, a pressure for the types of corpora available to expand as people want to study different things using corpora" (p. 172). The current study presents four very small collections of mainstream and ESL students' oral science explanation texts, prompted by a researcher or teacher in interviews. Like a corpus study, these collections were analyzed using computers to examine patterns of use. But unlike corpus analysis, the data were not standard references available to all researchers, and so they deviate from McEnery and Wilson's prototypical definition. The size of the collections in the current study limits their generalizability; for that reason they were held up for comparison to a larger corpus analysis of written science explanations (see Mohan et al., 2002). The aim of the current, small study was to explore similar variations in language use which have stood out when audience (reader) age and speaker age were compared. The results of the Mohan et al. study were presented in Chapter 2, and the results of the current study will be discussed in Chapter 8, based on the findings from each data chapter.

The analysis of the data in this study was done by using a computer to search and find the language features which had been identified in the literature as being relevant to causal explanations, following Mohan et al. (2002) and described also in Biber (1988). Because the collection sizes were small in the current study, each clause containing a relevant feature was copied to a new document which was saved and printed for hand verification. The lexical density analysis was carried out using the concordancing program *Monoconc* (Barlow, 1999), and *Range* (Nation, n.d.)

### 3.1.6 The design of the present study

As stated in Section 3.1.2, case study design is very eclectic in the methods it can utilize, and discourse analysis is an acceptable method within this design (Knobel & Lankshear, 1999). Text constructed in the natural, social contexts being investigated can be explored systematically using discourse and corpus analysis techniques, offering insight into the linguistically mediated meaning-making within that social context. In other words, the case studies offer the social contexts for collecting the discourse which is to be analyzed, and the analysis can lead to a deeper description and explanation of the social actions (causal explanations) occurring within those contexts. For these reasons, the research design chosen for this study is a qualitative, multiple case study design (Spradley's multiple social situations), with a systemic functional linguistic discourse analysis, including an analysis of the grammar based on Halliday (1994) and a social practice analysis based on Mohan (2003), carried out on the texts produced within each of the cases. This design is illustrated in Figure 3.6.

**Figure 3.6: The design of the present study**



### 3.2 Research procedures

As shown in Figure 3.6, data collection was carried out in each of four contexts, chosen to assist the researcher in her exploration of the research questions. The following sections will describe this study's sampling procedures, the research sites, and the participants.

#### 3.2.1 Sampling procedures

In order to find suitable sites to carry out this project, two sampling considerations needed to be addressed. The first involved finding two main topics in the curriculum which were taught at the target levels, which would be somewhat related, and which would easily generate causal explanations. The second consideration involved finding research sites where teachers would be teaching these topics to ESL and mainstream speakers. The two considerations became somewhat entwined as the researcher looked for topics as well as for teachers who were both teaching them and willing to participate in the project.

The first consideration involved examining the British Columbia Ministry of Education Integrated Resource Packages (IRPs) for suitable topics at the primary and high school levels. After examining these topics and talking with potential teacher-participants, a unit on magnetism was chosen for the primary contexts and the physical science topic of elements, compounds, and reactions was chosen for the high school contexts. According to the IRP for kindergarten to grade seven science (British Columbia Ministry of Education, 1995a), the study of magnetism is part of the grade two–three physical science curriculum. Among the prescribed learning outcomes for this topic are that students will be able to classify materials as magnetic or non-magnetic and demonstrate magnetic attraction and repulsion. Some of the recommended activities are to have students test whether magnets attract various items, record their findings, and draw conclusions from their inquiries to suggest, among other things, which features of the items lead to attraction. For these reasons, the study of magnetism was considered a productive topic for investigating students' causal discourse as they attempted to explain why certain items might be attracted.

The topic of elements, compounds, and reactions, according to the IRP, is part of the grade nine physical science curriculum. The prescribed learning outcomes for this unit include having students be able to "describe how elements are characterized by the nature of their particles," "compare and contrast physical and chemical changes," and "identify the effects of various factors on the rate of chemical reactions" (British Columbia Ministry of Education, 1995b). The IRP suggests that students need to understand the atom and the periodic table in order to be able to explain chemical reactions. This focus on effects and explanations suggested that this physical science topic would produce the types of explanatory causal discourse being explored by the present study.

These two topics were considered ideal for two key reasons. Even though they are taught at two widely differing age levels, they are potentially related in their use of causal language in at least one dimension: Magnets have positive and negative poles which cause different reactions when placed near other magnets, and atomic particles (protons and electrons) have positive and negative charges which play a role in how they bond with other atoms. These similarities in topic helped establish better grounds for comparison of causal language across the four contexts. The other reason these two topics were appealing was that there is a considerable amount of literature available concerning the teaching of these concepts. Given that the researcher is not a scientist but a language educator, the availability of relevant literature on these topics was considered an advantage.

Once the two topics were proposed, three schools were selected through informal channels, and four teachers were approached with requests to involve their classes in the project. The selection strategy for obtaining the samples can be considered purposeful sampling in that these classes were sought out as potentially information-rich contexts which would yield the needed data. Because "most ethnographers do not know in advance if potentially information-rich cases will yield valid data until they have completed a preliminary data analysis" (McMillan & Schumacher, 1993, p. 413), the researcher arranged to collect data from a number of classes which met the criteria for each case (see Table 3.1). One class from each context was chosen as the focal group for the discussions in the four data presentation chapters, but all classes were examined to ensure that the discourse of each focal group was representative of the entire database for that focal group.

### 3.2.2 Research sites

The data for this study were collected from the four different contexts listed in Table 3.1. In this section, each site will be described in detail.

**Table 3.1: The four research contexts**

| Name of class | Name of school | Grade level | Number of classes |
|---|---|---|---|
| Mrs. Sinclair's class | Summerside Primary | grade 1-2 | 1 |
| Mrs. Montgomery's class | Merrydale Elementary | grade 1-3 | 3 |
| Mr. Peterson's class | Western High | grade 9 | 3 |
| Ms. Armstrong's class | Western High | grade 8-9 | 2 |

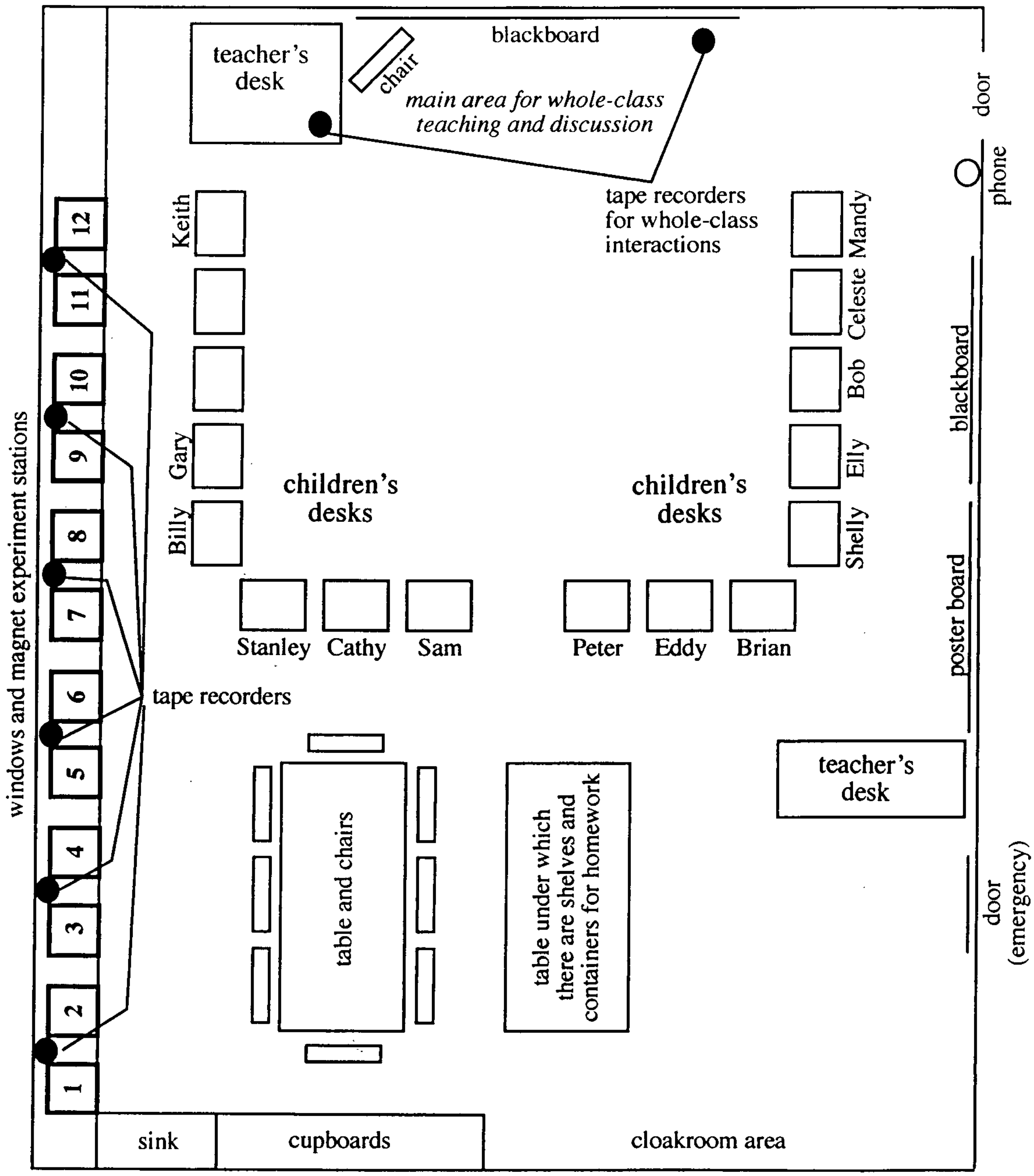
#### 3.2.2.1 Mrs. Sinclair's mainstream class at Summerside Primary School

Mrs. Sinclair's grade one and two science class was situated in a small suburban (almost rural) public school in a relatively high socio-economic area in Western Canada. The school was a primary school rather than an elementary school; upon finishing grade two, the children move to a different school within the same district.

Mrs. Sinclair's science class was held from 12:45 to approximately 1:20 on the afternoons of Monday, Tuesday, and Friday, in the same classroom which served the class for their other subjects (see Figure 3.7). The room was large and decorated with Christmas ornaments to reflect the upcoming holiday. Windows covered one full side, offering a view of a large field. The students' desks were arranged in a U-shape in the front half of the room, and the area in front of the teacher's desk, next to the blackboard, was the usual site for the children to sit cross-legged while engaged in whole-class discussions and teacher-fronted instruction. This area was used for the introduction to the magnet unit on Day 1 and for the question-and-answer period on Day 9 as well as for other subjects and story-telling time. The students returned to their desks once they had finished each experiment and waited for the next session to begin. Along the window, on a wide counter, were the twelve magnet stations, with station (experiment) number one in the far back area next to the sink, and station (experiment) twelve at the front of the room near the teacher's desk.

The written instructions for each experiment were in plastic sheet protectors taped to the counter at the appropriate stations, and all the materials the children needed were in small boxes positioned next to the written instructions. One audio-tape recorder was placed between each two stations so that six recorders were able to record the language of the children as they worked on their experiments. Two recorders were used at the front of the room during the whole-class interactions and were later moved to the station areas.

**Figure 3.7: Mrs. Sinclair's teaching area**



#### 3.2.2.2 Mrs. Montgomery's ESL class at Merrydale Elementary School

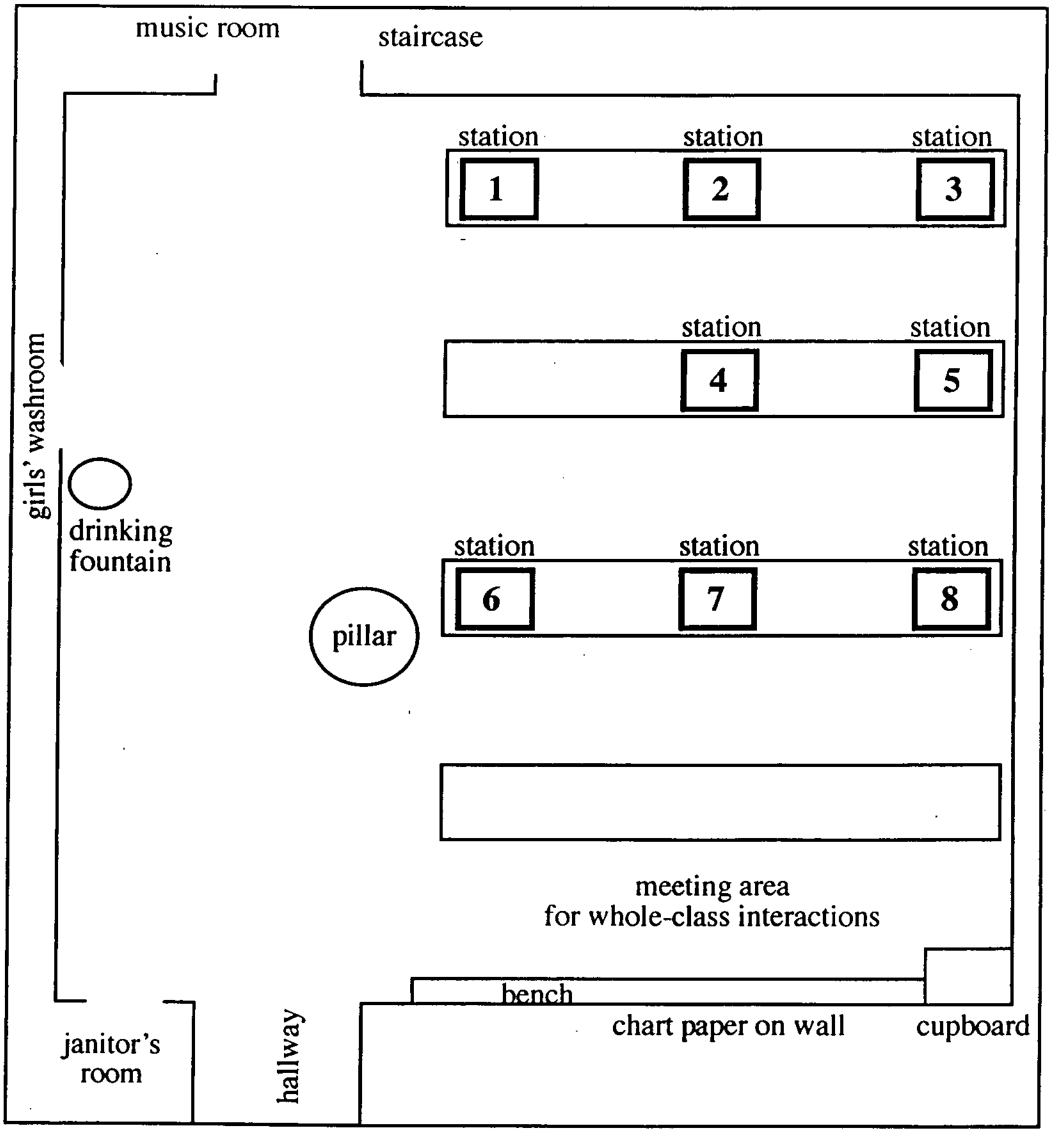
Mrs. Montgomery's classes were located in a major Western Canadian city, in a large inner-city public school which offered instruction from kindergarten to grade seven. The school had an ESL population of eighty-seven percent, according to Mrs. Montgomery, with a further eleven percent made up of Canada's First Nations students. The website for the school described the population as representing more than thirty cultural and linguistic groups of which the largest were Vietnamese, Cambodian, Filipino, and First Nations. According to Mrs. Montgomery, the school was attended by children whose families represented a lower socio-economic status than those associated with Mrs. Sinclair's school.

All of Mrs. Montgomery's magnet lessons occurred in the afternoons. She met with Class A first, from 1:00 to 1:40 p.m. As Class A left the area, Class B arrived and went from 1:40 to 2:20. Class C arrived at 2:20 and continued until the school bell rang at 3:00. One experiment, number seven (making a compass) took longer than the allowed time; as a result, Class C was cancelled and the students did not do that experiment.

The science classes for the magnet unit were held in one of the student lunchrooms, a large area in the basement of the school, with long tables and benches in rows (see Figure 3.8). During the lesson, it was typical to hear noisy children from other classes passing through the area or using the girls' washroom or the drinking fountain at the side of the area. Although there were windows near the ceiling on one side, the area was characterized by cement walls and floors with artificial lighting. The daily whole-class interactions which were led by Mrs. Montgomery prior to and after the hands-on experiments were held at one end of the room. She used masking tape to post chart paper on the wall, and on this she used felt markers to write words or draw diagrams to help the children understand the task. At this end of the area, Mrs. Montgomery reviewed the previous session's experiment, introduced the current experiment, had the children write their predictions in their magnet booklets, and gathered the children for a daily question-and-answer "debriefing" on the current experiment. The experiments themselves were done at eight stations set up just prior to Class A by the researcher on the tables around the room, each of which had an audio recorder to record the children as they worked. One recorder was relocated from where the whole-class interactions occurred, to one station, and returned again to the teacher-fronted discussion area so that all discourse interactions could be collected as clearly as possible.

Each of the eight stations had the same equipment, and all children did the same experiment at the same time. There were no written instructions at the station; Mrs. Montgomery went over the instructions verbally and visually before the children were assigned to their stations. Moreover, Mrs. Montgomery, the regular classroom teacher, and the researcher moved around to each group to make sure they understood the task and to ask the children questions about what they were doing.

**Figure 3.8: Mrs. Montgomery's teaching area**



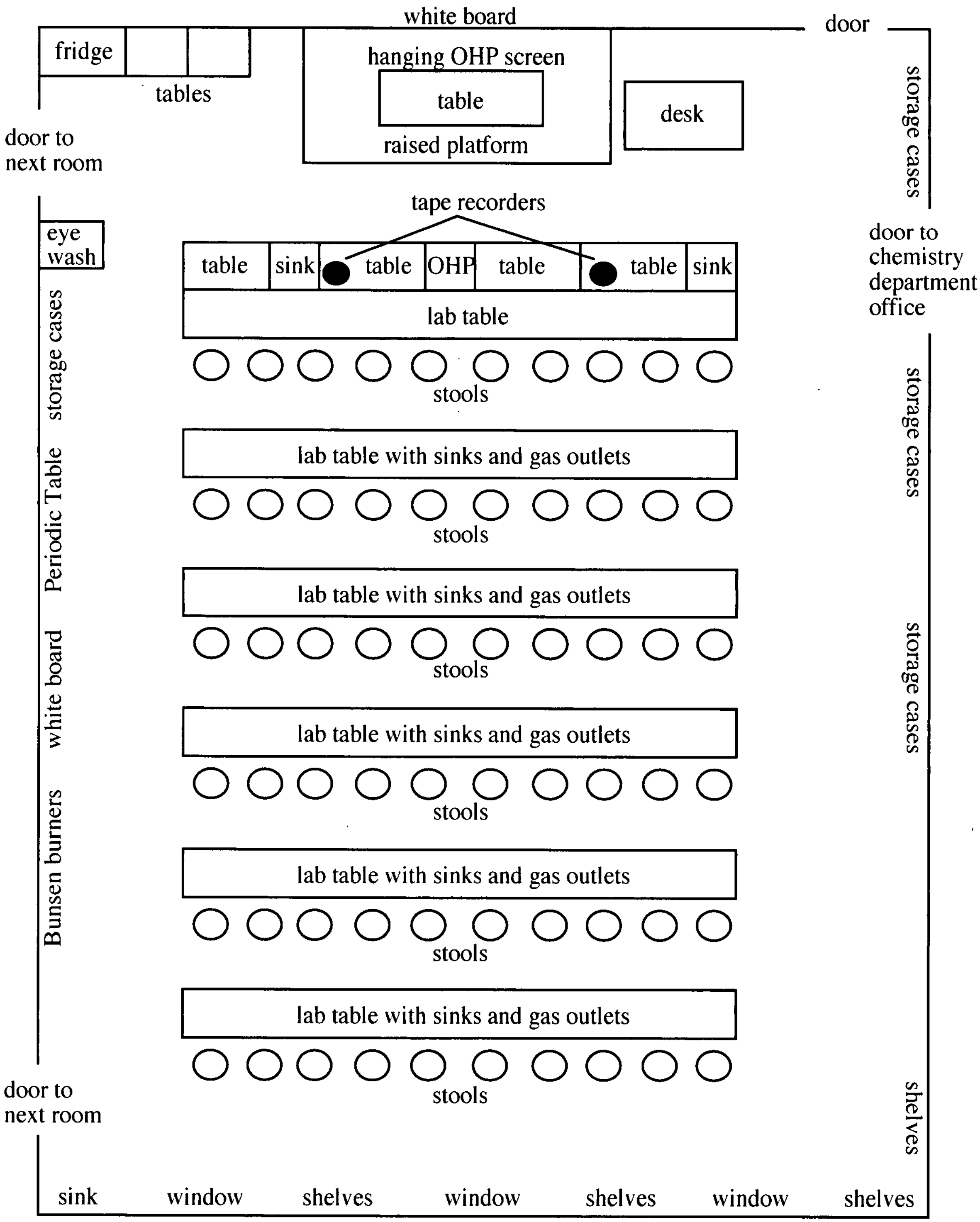
### 3.2.2.3 Mr. Peterson's mainstream class at Western High School

All three of Mr. Peterson's classes were held in one of the many science classrooms at Western High School, a secondary school which, according to information available through the web site for the school and the district, had at the time this study was done over 1500 students with more than three quarters of them coming from an Asian origin. The research project which involved these classes was carried out from the beginning of the school year in September to mid-November, when the unit finished. Two of Mr. Peterson's classes were held in the morning of every second school day, and the other class was held last period of the alternating days. The classes were usually eighty minutes long on Mondays, Tuesdays, Wednesdays, and Thursdays (8:35–9:55 a.m.; 10:10–11:25 a.m. with five minutes of announcements; and 1:50–3:10 p.m.) and sixty minutes long on Fridays (8:35–9:35 a.m.; 9:50–10:50 a.m.; 12:50–1:50 p.m.). The periods were marked by the sounding of a buzzer, and the students arrived and left when this buzzer rang. Class A, which is the focus of the discussion in chapter five, was held in the first period of the morning, followed by Class C. Class B was held on alternating days.

The classroom that Mr. Peterson taught in was a large room on a second-floor wing, joined to another science classroom by two doors. His office, which contained the equipment and materials for all the school's chemistry classes, was accessible by a door off the classroom (see Figure 3.9). The students sat on stools or tall chairs at the lab tables. There were three areas on each lab table which contained a sink and eight gas outlets; one area was on each end and one was in the middle. Most of the students sat in the first three rows from the front, and none sat in the back row.

Mr. Peterson usually addressed the students from the front of the classroom, near the table closest to his office, or next to the overhead projector (OHP), places where the two audio-recorders were set up. When the topic demanded it, he moved over to the Periodic Table which hung on the wall. For the first week of the unit, he stood at the side of the room using the white board to list physical properties. Demonstrations were done either on the table near the OHP or on the table which sat on the raised platform at the front of the room. Students were encouraged to move forward when the demonstrations were done on the raised platform.

**Figure 3.9: Mr. Peterson's teaching area**



The students' hands-on work, two labs which used time in two consecutive class days, was done in pairs and rare trios near the sink and gas areas of the lab tables. Mr. Peterson went over the procedures at the front of the room before the students began their labs. During the labs he circulated, making sure students were succeeding with their tasks and answering questions. During this time, the researcher also circulated, helping with the procedure and answering and asking questions. At other times, she sat on a stool at the last or second-to-last lab table, near the back sink.

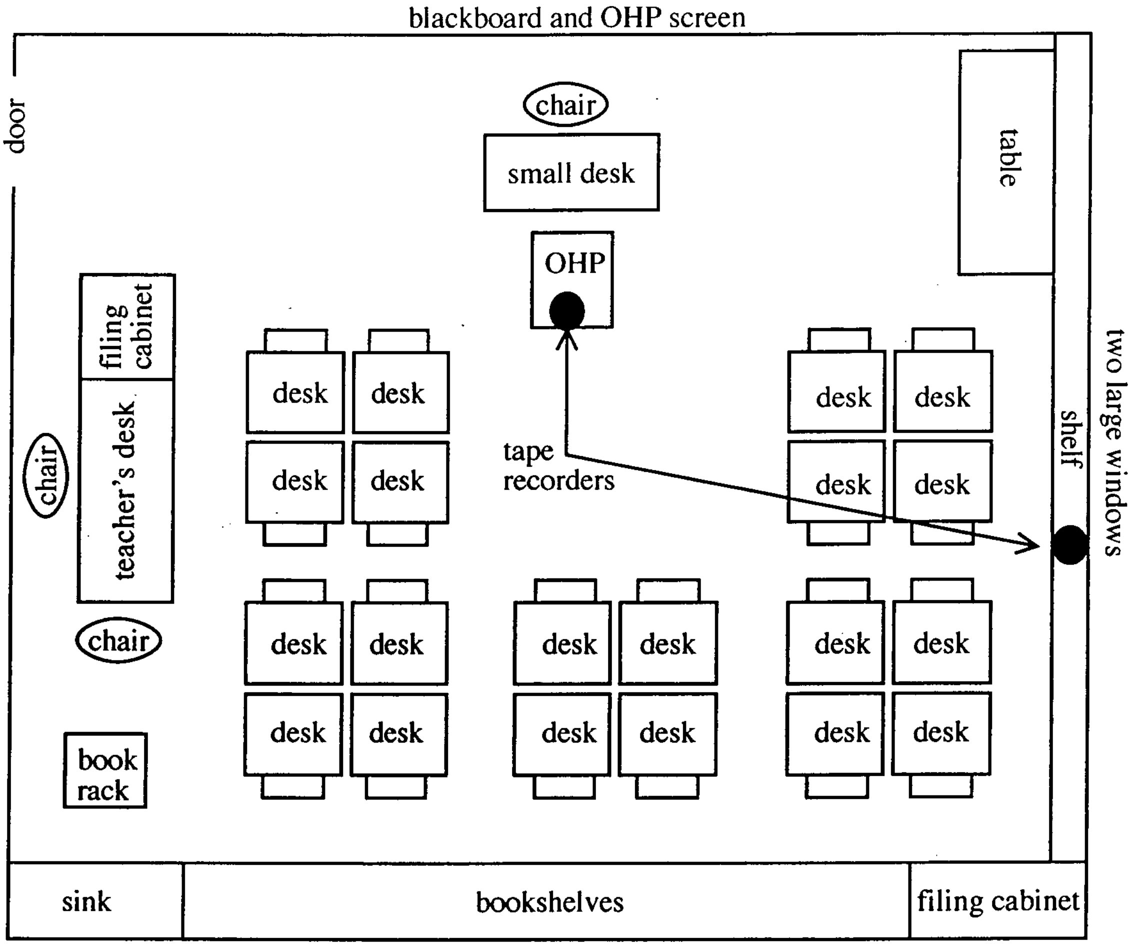
#### 3.2.2.4 Ms. Armstrong's ESL class at Western High School

Whereas Mr. Peterson's classes were held in Western High's science labs, Ms. Armstrong's two ESL science classes were held in a non-science, multipurpose classroom with windows overlooking visitors' parking and another wing of the school. As shown in Figure 3.10, the students worked together in five clusters of four desks except when they wrote tests or quizzes, watched videos, or did other similar activities, at which time Ms. Armstrong asked the students to lift up their desks and turn them so that all students were facing forward. The teacher typically stood near the front table and the OHP to address the whole class, and circulated around the small room when the students were working in groups. An audio-recorder was placed on the shelf under the OHP to capture the teacher's discourse and any talk directed towards her. A second recorder was placed on the ledge next to the window to pick up any talk at that side of the room. At times a recorder was placed on the teacher's desk at the side of the room or in the shelves at the back. During group work the researcher sometimes carried a hand-held recorder with her as she talked with the students and asked questions. During most of the class time, the researcher sat on the chair between the teacher's desk and the sink.

The research covered the period of January to June, and when it began in January, Class A and Class B met every other day. On Mondays through Thursdays, the class times were from 12:25 to 1:45 p.m. (Class A) and 1:50 to 3:10 p.m. (Class B), and on Fridays, the shorter classes ran from 10:55 a.m. to 12:00 noon (Class A) and 12:50 to 1:50 p.m. (Class B). At the end of January, the class times shifted, and Class A met every other day from

10:10 to 11:35 a.m., except for the shorter class on Fridays, from 10:55 to 12:00 noon. Class B met on the same day, but from 12:25 to 1:45 Mondays through Thursdays, and 12:50 to 1:50 on Fridays. Early in April, the class times again shifted, and Class A moved to 8:35 to 9:55 a.m. (Mondays through Thursdays) and 8:35 to 9:35 a.m. (Fridays). Class B followed Class A, from 10:10 to 11:25 a.m. (Mondays through Thursdays) and 9:50 to 10:50 a.m. (Fridays).

**Figure 3.10: Ms. Armstrong's teaching area**



### 3.2.3 Participants

The participants in this study represent a wide background of languages, ages, and abilities. All those whose words were captured for this study agreed to participate in advance and signed consent forms to this effect. Parents signed on behalf of the school children. All names used are pseudonyms and do not necessarily represent the participants' cultural backgrounds.

#### 3.2.3.1 The participants in Mrs. Sinclair's science class

At the time her class became involved in this research project, Mrs. Sinclair had been teaching in elementary schools in Western Canada for eighteen years, during which time she had taught grade two for four years, grades one, three, four, and kindergarten for one year each, and had spent the remaining ten years as a Learning Assistance and Integration Support Teacher for grades kindergarten through six in various schools. Her areas of specialization were Language Arts (major), Special Education (minor), and Early Childhood Education (minor). Mrs. Sinclair had been teaching at Summerside Elementary for three years, and was teaching primarily math, science, and social studies in this grade one/two split class (which she considered grade two because there was only one grade one student enrolled in it) from 11:55 a.m. to 2:25 p.m., Monday through Friday. Another teacher taught the class in the morning.

There were fourteen children in Mrs. Sinclair's class, nine boys and five girls. All students, and their teacher, were monolingual English speakers. Thirteen of the children were seven years old at the time the unit was taught. The fourteenth child, a girl (Celeste), was six years old and therefore officially a grade one student. One boy in the class (Keith) had frequent behavioral outbursts due to perceived medical difficulties and thus was often sent to a quiet room. Because of this, he was absent from class on Tuesday, December 5, and Friday, December 8. Two other boys (Bob and Billy) were absent on Monday, December 18, and Cathy was absent on Monday, December 4. Mrs. Sinclair was away Friday, December 15, and consequently the researcher was also absent; a teacher-on-call helped the students complete one experiment, which was not recorded or included in the data because of this.

**Table 3.2: Mrs. Sinclair's student pairs**

| Student pairs | Position on Day 1 |
|---|---|
| Peter (M) and Billy (M) | Station 1 |
| Gary (M) and Eddy (M) | Station 3 |
| Stanley (M) and Mandy (F) | Station 5 |
| Celeste (F) and Elly (F) | Station 7 |
| Cathy (F) and Sam (M) | Station 9 |
| Keith (M) and Shelly (F) | Station 11 |
| Brian (M) and Bob (M) | Station 12 |

The children were assigned to pairs by the teacher based on her assessment of their personalities and her opinion regarding how well they worked together. Each child worked with the same partner throughout the twelve experiments, and worked alone if his or her partner was absent. There were three pairs of boys, one pair of girls, and three mixed pairs for a total of seven pairs of children (see Table 3.2).

#### 3.2.3.2 The participants in Mrs. Montgomery's science classes

When this study was undertaken, Mrs. Montgomery was in her twenty-second year of teaching. Thirteen years of this had been spent as an elementary school teacher in a central Canadian province where she had a small population of ESL students in her classes and the school was located in a moderate socio-economic area. The remaining years had been spent in an assortment of ESL teaching positions in a low socio-economic area of a major western Canadian city. Her positions included teaching district ESL classes and doing ESL support teaching, and for the past few years she had been an Inner City Project Teacher at Merrydale Elementary School, working to "bring the community to the school, to form that bridge" (interview with teacher, February 5, 2002) and to teach the children of Merrydale both English and content.

Mrs. Montgomery stated that she loved to do hands-on science and math with the children because the hands-on nature allowed the children to become engaged with language as they did their tasks and later made sense of them. In her position at Merrydale School, she frequently offered science and math classes for children who were pulled out of their regular classes to participate. For the magnet unit, however, Mrs. Montgomery invited all the members of three classes to participate. The students' regular teachers attended and interacted with the children as well, although they did not lead the whole-class discussions or do any extended activities outside of the meetings reported here.

There were three magnet classes involved in the study, although the discussion will focus on only one of them. All three classes were taught using the same format, and the transcriptions revealed that the language produced by the children in the three classes was remarkably similar. Table 3.3 summarizes the three classes as far as the children's grades, genders, and first languages. As revealed by Table 3.3, Mrs. Montgomery's classes had high numbers of children whose first language was not English, information which was based on forms collected from the parents by school administrators.

The class which provided the discourse examples for the discussion in this thesis was Class A, the grade one–two split class, the same age group as that in Mrs. Sinclair's class. As Table 3.3 shows, this class was made up of twenty-one students of which twelve were boys and nine were girls. Ten of the students (five boys and five girls) were in grade one and were therefore six years old at the time of the study (one child turned six during the magnet unit). The remaining eleven children (seven boys and four girls) were in grade two. Of these, one boy was not yet seven years old; the other grade two children had already passed their seventh birthdays. Only three of the twenty-one spoke English as a first language, and all three were grade two, seven-year-old children.

Of the six children who were later interviewed, three were from Class A. One of the three was a grade one girl (Hannah) whose first language was Tagalog. The other two, Jack (a Mandarin speaker) and Aaron (an Urdu speaker) were seven-year-old grade two boys. Two seven-year-old girls from Class B were interviewed as well. One, Trish, spoke Croatian as her first language, and the other, Sandra, spoke Mandarin at home. Barbie, a seven-year-old grade two girl whose first language was Vietnamese, was the only student from Class C who participated in the final interview session. These six children were recommended (among others) for the interviews by Mrs. Montgomery because she felt that they would not be shy to use whatever linguistic and non-linguistic resources they had to answer the researcher's questions about magnets. Many of the children, the teacher reasoned, would be too shy to talk with someone they did not know well, even if they had the language to do so.

**Table 3.3: Mrs. Montgomery's three classes**

| | Grade | No. of students | No. of boys | No. of girls | First languages spoken |
|---|---|---|---|---|---|
| **Class A** | 1/2 | 21 | 12 | 9 | Chinese<br>Cantonese: 2<br>Mandarin: 3<br>Unstated: 2<br>Tagalog: 4<br>Vietnamese: 4<br>English: 3<br>Russian: 1<br>Tamil: 1<br>Urdu: 1 |
| **Class B** | 2 | 22 | 11 | 11 | Vietnamese: 7<br>Tagalog: 4<br>Cambodian: 3<br>Chinese<br>Cantonese: 2<br>Unstated: 1<br>English: 3<br>Spanish: 2 |
| **Class C** | 2/3 | 22 | 13 | 9 | Chinese<br>Cantonese: 4<br>Mandarin: 2<br>Unstated: 2<br>Tagalog: 4<br>Vietnamese: 4<br>Tamil: 2<br>Cambodian: 1<br>Croatian: 1<br>English: 1<br>Filipino: 1 |

For the first experiment, the children were assigned to groups of two or three by their regular classroom teachers who knew their personalities and strengths. From the second day on, however, groupings were typically made by calling names in the order of the magnet booklets that had been collected at the end of the previous session. Students therefore did not always work in the same groups, although at times certain children asked to be placed in the same group together and were given permission to do so. No student was required to work alone because of absenteeism.

#### 3.2.3.3 The participants in Mr. Peterson's science classes

Mr. Peterson was serving as the head of the science department at Western High School, a job that he had been doing for several years when this study was carried out. He had trained as a science teacher, specializing in high school chemistry, twenty years earlier, and teaching grade nine science was a regular part of his job. He also taught grade twelve chemistry and advanced placement (AP) chemistry, which provided high school students with the equivalent of first-year university chemistry. In the year that this study was conducted, Mr. Peterson was the only mainstream grade nine chemistry teacher at Western High.

There were three classes of grade nine science which participated in this research, and all three followed a similar teaching pattern. Although the discussion in Chapter 5 concentrates on one of the classes (Class A), as with the other multiple groups within a context, the data from the two other classes were examined to establish that the focal group was not exceptional in any key ways which would affect the findings of the study. Table 3.4 summarizes the three classes with regards to numbers, genders, and languages usually spoken at home. All students were in the age group of fourteen to fifteen years old. As previously noted, Western High had a large number of students from Asian backgrounds, so the students were asked to state which language they usually spoke at home. Out of the twenty-three students in Class A who claimed they usually spoke English at home, seventeen said they also spoke a Chinese language at times. In Class B, four out of the twenty students who usually spoke English at home also spoke Chinese at times, and in Class C, twelve of the nineteen spoke Chinese as well as English at home.

Class A was chosen as the focus of the discussion because it was neither the most participative group regarding science topics and nor was it the least. According to the teacher, there were some students in the class who spoke up and answered questions often, although the group as a whole did not stand out as being strongly participative. Also

**Table 3.4: The participants in Mr. Peterson's science classes**

| | No. of students | No. of boys | No. of girls | Languages usually spoken at home |
|---|---|---|---|---|
| **Class A** | 29 | 17 | 12 | English: 20<br>Chinese<br>Cantonese: 4<br>Mandarin: 3<br>Vietnamese: 1<br>Indonesian: 1<br>Korean: 1 |
| **Class B** | 30 | 14 | 16 | English: 23<br>Cantonese: 3<br>Korean: 2<br>Hebrew: 1 |
| **Class C** | 29 | 7 | 22 | English: 19<br>Chinese<br>Cantonese: 3<br>Mandarin: 6<br>Korean: 1 |

considered in the choice was that the average scores for homework and lab reports for this group also gave the impression that it was in the middle of the other two classes. Moreover, consent to participate in the research study was much higher in Class A than it was in the other two classes, another factor in choosing this group as the focal participants.

There were nine students who participated in the lunchtime interviews. Two female students from Class A, Stella and Andrea, met with the researcher once and were asked to talk about the experiment they had done and then to tell her about it, answering *why* and *what happened* questions asked. Three boys from Class B—Zachary, Ivan, and Edward—were also interviewed, Edward once, and Zachary and Ivan twice. As with the girls in Class A, Zachary and Ivan were asked to talk about the experiments or demonstrations, then tell the researcher about them, and answer her questions. Because he was interviewed alone, Edward simply answered the researcher's questions about what he had done, what had happened, and why it had happened. From Class C, four students were interviewed, one pair of girls as in Class A (Sara and Jeanie) and two individual, one-on-one interviews, one with a boy (Mark) and a girl (Heather). Heather was a Korean ESL student who had come into this class from the previous year's ESL science but was finding the mainstream course challenging. The other eight students who participated in the interviews spoke English confidently and native-like. The nine students were chosen as they represented a wide variety of abilities in science based on their written performance as well as their oral participation levels.

#### 3.2.3.4 The participants in Ms. Armstrong's science classes

Ms. Armstrong was an experienced ESL teacher with nineteen of her twenty years of experience spent teaching ESL including ESL science. The areas she specialized in during her teacher education program were ESL, English, and drama, but over the years she had built up a selection of science materials and a good reputation for teaching ESL science in the early high school grades despite not being a science specialist. She had not been teaching ESL science for the two years prior to the one in which the study was conducted because the school had not offered the program. The course had been brought back for the current year, but it was uncertain whether the school would continue to offer it in the following years. In the event they did, it would not be Ms. Armstrong who would teach it as she was planning a transfer to another school. Most of the equipment Ms. Armstrong had acquired over the years had been returned to the science department two years earlier and had not been reclaimed for the two classes she was teaching this year.

As Table 3.5 shows, the two classes were made up of mostly speakers of the Chinese languages. Most of the students did not specify which Chinese language they spoke or where they came from, but they understood each other and often communicated loudly in their first language during group activities. In both classes, most of the students were male, and all but one were in grade eight or nine (thirteen to fifteen years old). Class A was the focal class, chosen primarily because the students spoke up more often and more clearly than those in Class B, and because they also represented a slightly more diverse group linguistically. As noted earlier, however, data from all classes were examined to ensure that the focal class was representative of all groups within the context.

**Table 3.5: Ms. Armstrong's two classes of ESL science**

| | No. of students | No. of boys | No. of girls | First language |
|---|---|---|---|---|
| **Class A** | 20 | 15 | 5 | Chinese: 15<br>Korean: 2<br>Japanese: 1<br>Arabic: 1<br>Spanish: 1 |
| **Class B** | 18 | 12 | 7 | Chinese: 13<br>Korean: 3<br>Farsi: 1<br>Spanish: 1 |

According to Ms. Armstrong, many of the students in both classes exhibited behavior which made it difficult for her to engage them in hands-on activities, and this was the main reason why she hadn't reclaimed the science equipment or taken them on trips to the library. She considered the students to be noisy, disruptive, and immature, although she admitted that their behavior had improved since September. During the researcher's observations, there were very few days when no students were given detention; usually at least one student and sometimes three were told to stay at lunch or after school to "practice being quiet." It seemed that the same students were always at the center of trouble.

There were five students—three boys from Class A and two girls from Class B—who gathered in two groups in the classroom at lunchtime to do problem-solving tasks for the researcher. Each group met for about twenty-five minutes, five times, over a two-month period beginning in late April and finishing in early June. These meetings were audio-recorded. They began with a brief introduction to the problem by the researcher, then the students worked on the problem together. When they had finished, they called the researcher over and gave their answers to the problems as well as responded to the researcher's questions.

These five students were recommended by Ms. Armstrong because according to her, they could be trusted to take their learning seriously and would therefore turn up and make a good effort to speak English. The researcher had also observed these five students and had agreed with the judgment of the teacher. Two of the three boys, Ken and Tony, were from Taiwan and spoke Mandarin. The other boy, Keifer, was Japanese. Of the girls, Vicki spoke Mandarin and Belinda was a Farsi speaker.

### 3.3 The role of the researcher

The researcher's role as a participant observer shifted between what Spradley (1980) referred to as *passive participation,* in which "the ethnographer… is present at the scene of action but does not participate or interact with other people to any great extent" (p. 59) and what he termed *active participation,* where the researcher "seeks to *do* what other people are doing" (p. 60, italics in original). The lower participation levels occurred in the more teacher-fronted, lecture-style high school science classes. In the hands-on inquiry of the early elementary science classes, however, the researcher's role was to help the teacher facilitate these experiments by interacting with and helping the children at their various stations. The researcher, therefore, filled multiple roles depending on the wishes of the individual teachers and the nature of the classroom interactions.

### 3.4 Data collection procedures

As mentioned in an earlier section and illustrated in Figure 3.5, data collection procedures included observations of whole-class interactions, observations of small group interactions including student–student, student–teacher, and student–researcher interactions, interviews of students in which they were asked to express their understanding of particular topics related to their course of study in science, and the collection of relevant samples of produced texts (e.g., laboratory reports, written explanations, tests) and relevant instructional materials. The magnetism unit produced roughly 116 hours of recorded discourse, approximately 25 hours from Mrs. Sinclair's class and about 91 hours from Mrs. Montgomery's. The physical science unit in the high schools resulted in approximately 138 hours of recorded data, roughly 71 hours from Mr. Peterson's classes and 67 hours from Ms. Armstrong's. Table 3.6 summarizes the database.

**Table 3.6: The database**

| | recorded observations | recorded interviews | field notes | instructional materials | student work |
|---|---|---|---|---|---|
| **Mrs. Sinclair's class** | 24 hours | 60 minutes | ✓ | • magnet booklets<br>• station instructions<br>• board work | • completed magnet booklets<br>• written tests |
| **Mrs. Montgomery's class** | 90 hours | 65 minutes | ✓ | • magnet booklets<br>• poster work | • completed magnet booklets<br>• writing |
| **Mr. Peterson's class** | 68 hours | 165 minutes | ✓ | • textbooks<br>• handouts<br>• board work<br>• OHP work | • lab reports<br>• sample of text answers |
| **Ms. Armstrong's class** | 62 hours | 300 minutes | ✓ | • textbooks<br>• handouts<br>• board work<br>• OHP work | • lab reports<br>• creative writing task |
| **Totals** | **244 hours** | **9 hours & 50 minutes** | | | |

### 3.4.1 Observations

Descriptive observations of whole-class interaction served two primary purposes. The first purpose allowed the researcher to follow what was being taught so that she could be informed during small group interactions and interviews. The second was to examine how the teachers were modeling causal discourse through, for example, their choice of questioning strategies and interactions with class members. These observations were audio-taped with two or more recorders set up in areas of the room which allowed the best pickup of voices. These audiotapes were transcribed by the researcher. To supplement the recordings, the researcher took detailed field notes during each science lesson, writing down the names of the speakers as they spoke and noting their discourse as accurately as possible. This was because students' voices could, at times, be too soft to be audible on tape; having a written record of the response assisted with transcribing. The descriptive observations of the whole-class discourse moved from what Spradley (1980) termed "grand tour observations" (p. 77), in which an overall feeling of the interaction is the goal, to "mini-tour observations" (p. 79), in which the researcher considers specific questions such as "Which actors participate in which events?" (p. 81). This question was particularly important because the answers, along with the teacher's recommendations, helped establish which "actors" would be invited to participate in the formal interviews.

Small group interactions between students, between students and the teacher, and between students and the researcher were also audio-recorded with field notes taken wherever possible. These group activities included the experiments which the primary school students carried out at various stations set up around the room. Audio-tape recorders were positioned at or between these stations depending on the layout of the room (see descriptions of the rooms in Section 3.2.2). During small group interactions, the researcher needed to participate actively at the same time as she observed, maintaining a "dual purpose" in which she attempted "to participate and to watch... others at the same time" (Spradley, 1980, p. 58). Field notes during this level of participation were written immediately after these types of interactions.

### 3.4.2 Interviews

According to Spradley (1980), "an informal ethnographic interview occurs whenever you ask someone a question during the course of participant observation" (p. 123). Given this definition, several opportunities for informal interviews arose, particularly when the researcher was in the role of active participant during the hands-on activities. The researcher also carried out formal interviews, those which were requested and scheduled, with six of the primary school children and small groups of high school students to elicit explanations as they explored their understanding of a topic. The students who participated in these interviews were chosen from their classes based on their enthusiasm as observed by the researcher and on the recommendations of their teacher; this purposeful sampling was carried out to reduce the chances of students being unable or unwilling to respond.

At the primary school level, a twenty- to thirty-minute whole-class interview was held in the discussion area of the classroom by the regular classroom teacher, Mrs. Sinclair, on the last day of the unit. Six of Mrs. Montgomery's students came individually for short, five-minute interviews with the researcher in Mrs. Montgomery's office approximately one month after the last writing exercises were completed. In the high school, as mentioned above, nine of Mr. Peterson's students, either individually or in pairs, met with the researcher for five to fifteen minutes in their regular science classroom once or twice at lunchtime while the unit was being taught. Five of Ms. Armstrong's students—one group of three boys and one group of two girls—met with the researcher on five occasions at lunchtime in their regular science classroom. These five students met for approximately twenty-five minutes on each occasion. All interviews were audio-recorded and transcribed.

Most of the interviews at the high school followed a somewhat different format, as indicated above. The five students from Ms. Armstrong's class were first asked about what they were learning in the science class, and then given a problem to discuss without the researcher present. After they had solved the problem, the researcher asked questions about their findings. The rationale for proposing this particular interview structure is that it offered not only a wealth of discourse about the topic, but also an opportunity to see whether the context of the social action influenced language choice; the format created an information-rich context in which students were constructing explanations orally both in an informal type of situation (together with their peers), and then offering that explanation to someone whom they do not know as well (the researcher). A similar format was followed for the three pairs of students from Mr. Peterson's class, but rather than presenting them with a science problem, these students were asked to discuss their lab experiments and the demonstrations they had been involved in. Once they had discussed these with their partner, the researcher asked questions. The three individual students from Mr. Peterson's class were interviewed about their lab experiments by the researcher.

### 3.4.3 Documents

Whereas documents in qualitative research typically refer to historical texts and artifacts (McMillan & Schumacher, 1993), in this study they refer to written instructional materials and student-generated texts. These were collected to help give more context to the field notes and recorded interactions. For example, there were times when Mr. Peterson referred in class to questions posed by the textbook and assigned for homework, and having the documents therefore helped to contextualize the discussion. Ms. Armstrong depended heavily on written texts for many of her lessons. Having the instructional text as a document also helped to understand what science language was being presented to the younger students.

The student-generated texts were not fully exploited in this study, although they were referred to when questions of language uptake or content understanding arose. They remain unanalyzed for future exploration into students' constructions of scientific explanations.

## 3.5 Data analysis and presentation

Before beginning the discourse analyses, the oral data which was collected on audio-tapes were transcribed, typed into a word-processing program, and printed out for examination. The files of interview data, which were to be used as the small corpora for the quantitative examination, were copied, and from these copied files, the interviewer's comments and questions were deleted so that only the students' words remained in the files. The analysis and presentation of these data are described in Section 3.5.2.

The classroom interaction data were supplemented by the field notes taken during the observations, notes which greatly facilitated the transcription process. By using the field notes, the researcher was able to identify many of the speakers and fill in some of the interactions which were otherwise too quiet for the tape recorder's microphone to pick up satisfactorily.

Given Halliday's notion of the two types of patterning in teaching science and the importance of both the concepts and the causal relations among them, the analysis moved forward by examining the data to list the concepts which, by their frequency of repetition in the classroom discourse, could be considered main concepts in the unit. These concepts were later represented in the concept maps drawn for each context. The lists were compared, and three key concepts from each age group were chosen for close examination. The data concerning these three key concepts are presented in each of the four data chapters in the section called "Tracking the construction of three key concepts."

The data were also examined by looking closely for evidence of attempts at explanations and of patterns of causal relations, using the types of language features previously identified by the literature (see Mohan et al., 2002). These features included examples of relations such as *X causes Y; X because Y; if X, then Y; when not X, then not Y;* and so on. Examples of contextual clues, such as responses to *why*-questions and *how*-questions, were also identified.

The classroom interaction data are presented in as much detail as possible in the four data chapters, primarily as a narrative description of the activities occurring in the classroom and the discourse constructing those activities, but at times quantified in charts (see, for example, Table 4.11). The explanations which concern the key concepts in the four data chapters are included in full from the data; where the explanations were repeated in the data, either all attempts are presented in the chapter narratives, or the clearest representations are offered. The purpose of the narratives is to provide the reader with a deep understanding of each of the four contexts. The narratives are presented following Halliday's two types of patterning, discussing taxonomy construction separately from the language features used to related concepts logically and causally.

Also included within the narratives at times are systemic functional grammar analyses of the knowledge which the language is constructing, as per Halliday (1994), and graphics—particularly classification trees—of the knowledge structures being introduced (see Mohan, 1986, for a full discussion of knowledge structures). These are offered to help the reader understand more deeply what appears to be happening at the classroom level.

### 3.5.1 Social practice perspective revisited

Social practice theory analysis (Mohan, 1989, 2003) is used in Chapter 8 to reveal the way the four teachers are working with their students to develop causal explanations and understandings in their respective classes. This analysis method transforms selected discourse from the data chapters into charts which reveal the moves between practice and theory, through specific and general reflection. Whereas the basic idea of the theory/practice interaction was offered in Section 3.1.4 of this chapter, Table 3.7 presents an example of the data analysis which accompanies the comparison of the classroom discourse in Chapter 8. This type of data analysis, based on social practice theory, is the primary analysis used to respond to research question one in Chapter 8.

**Table 3.7: The data as action and reflection discourse**

| Speaker | Specific reflection | General reflection | Other |
|---|---|---|---|
| Teacher | I've got some water here well I've got water and I've got alcohol and I'm not telling you which one is which... How would you tell the difference? | | |
| Students | Smell. | | |
| Teacher | There you go. | There's another physical property. See water and alcohol you can't tell the difference between them by looking at them. But... smell will do it. | |

### 3.5.2 Corpus analysis revisited

Section 3.1.5 discussed corpus analysis in general as well as described the process through which this study identified the language features in the data. As with previous corpus studies, this study quantified the features and presented them as the number of items (or *tokens*) which belong to each classification feature (or *type*). Although the data chapters present the quantitative data as types and tokens which appear in the transcripts, the frequency counts in Chapter 8 have been normalized to a text length of 1000 words unless otherwise stated, following Biber (1988), to allow for a comparison across texts which otherwise vary in length. Even with this normalizing, however, the number of some features which are rarely used may not be an accurate representation of the texts; Biber et al. (1998) offered caution about the possibility of artificially inflated findings from this normalizing and suggested further reduced text lengths if the average texts within the corpus are short. Although this study chose to maintain the 1000-word length, it regularly cautions the reader about inflated findings during the discussion in Chapter 8.

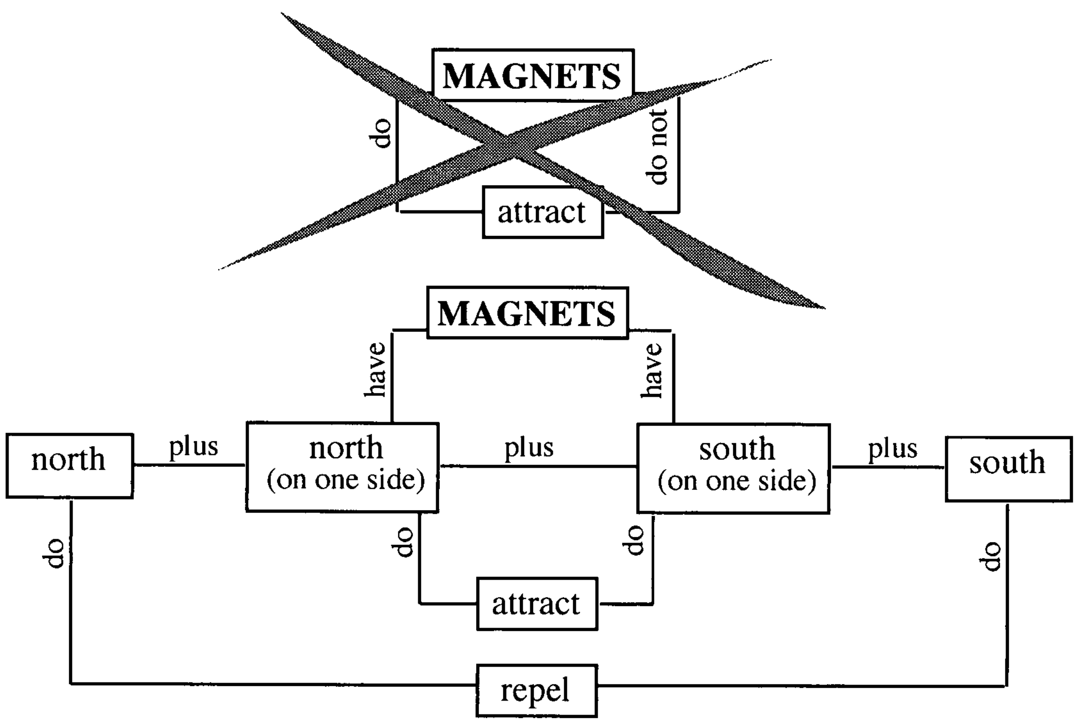
### 3.5.3 Concept mapping revisited

Chapter 2 discussed how Joseph Novak used concept mapping to investigate concept learning. He had his followers draw concept maps from the information brought up by students in interviews to document changes in the children's knowledge of science. This study uses a similar strategy to map the concepts which were presented and taught in the science classrooms and the connections which were made among them. The maps were created with the key ideas being presented by the teachers; there were many ideas brought up within the data collection period in each context, but the resulting concept maps in this thesis offer only a representation of the key ideas to give the reader an understanding of the complexity of the topic and the types of concepts being discussed, as well as the language typically used. In other words, the maps are not being presented as an analysis, but as an overview of the main concepts taught and used by the interactants in the four contexts.

When constructing the concept maps in this study, the discourse was examined closely for the concepts and their relations, and a draft was made from that discourse. As the interactions continued, parts were added to the drawing as new concepts were presented, as per Novak (n.d.), who maintained that concept maps are never finished and therefore undergo many revisions. Every effort was made to ensure that the drawn connections represented the discourse throughout the unit, as used by the interactants. The following discourse excerpt from Mrs. Montgomery's class has been drawn to offer an example of process used for mapping the discourse (see Figure 3.11):

| | |
|---|---|
| Teacher | What did we discover? |
| Student | Magnets attract. |
| Teacher | Let Jack finish. |
| Jack | Because if you turn it around it won't attract and if you turn it around it'll attract. |
| Teacher | So it has a north and south? Yes it does. And is it all on the same side of the magnet? |
| Jack | No. |
| Teacher | No. One side of the magnet will be? |
| Jack | North. |
| Teacher | And the other side of the magnet will be? |
| Students | South. |
| Teacher | Right. And when we have two souths coming together they are going to? |
| Student | Um repel. |
| Teacher | Repel. If we have norths coming together they are going to? |
| Student | Repel. |
| Teacher | If we have a north and a south coming together they're going to? |
| Students | Attract. |
| Teacher | Attract. Just like the other magnets. |

**Figure 3.11: The process of concept mapping**



In Figure 3.11, the smaller map, which shows only that magnets *do attract* and *do not attract,* was crossed out in favor or the more expanded map, which includes *north, south,* and *repel.* Both these maps were revised to create the map in Chapter 5 (Figure 5.3), which contains the concept map drawn from the complete discourse. It is important for the reader to be aware that the larger, revised maps, such as the one in Figure 5.3, represent the knowledge which the teacher was constructing with the students in the class and not necessarily the knowledge that each individual student in the class had once the unit was finished. As previously noted, the maps are composites of the key ideas discussed in the classroom and not analyses of the constructed knowledge.

This section has presented the key data analysis formats as well as offered a preliminary look at the way the data are presented in each format. The next section will discuss the trustworthiness of the study's design and reporting.

### 3.6 Research design trustworthiness

It is widely accepted that researchers cannot help but make assumptions about the social contexts they are in and that these assumptions can influence the way they collect, interpret, and present their data (Hammersley, 2000). Moreover, when developing theory, according to Hammersley, "once a particular interpretation, explanation or theory has been developed by a researcher he or she may tend to interpret data in terms of it, be on the look out for data that would confirm it, or even shape the data production process in ways to do this" (p. 2). As this type of bias threatens the reliability of the study, Yin (1994) recommended that "the general way of approaching the reliability problem is to make as many steps as operational as possible, and to conduct research as if someone were always looking over your shoulder" (p. 37). This can be attempted by making explicit six aspects of the design—researcher role, participant selection, social context, data collection strategies, analysis strategies, and analytical premises (McMillan & Schumacher, 1993). By describing the selected cases and presenting the analysis of the discourse in an explicit and transparent way, the reader can follow the arguments and evidence from the research questions to the conclusions and make his or her own judgments. This "chain of evidence" (Yin, 1994, p. 98) is one of three "principles" which aim to increase the reliability of case study designs; the other two are creating a case study database and using multiple sources of data. The researcher followed both. Not only did the study use multiple sources arising from the cases, such as classroom and small group oral interaction, teacher- and student-produced written work, and textbooks, as mentioned earlier, it prepared both qualitative and quantitative databases for analyses. It also held its quantitative findings up against a larger study for comparison.

Regarding issues of validity, two important points must be kept in mind. First, as Yin (1994) stated, "internal validity is a concern only for causal (or explanatory) case studies, in which an investigator is trying to determine whether event x led to event y" (p. 35). No such cause–effect relationship is being attempted in this study, and therefore threats to internal validity, such as history, maturation, observer/researcher effects, selection, attrition, or alternative explanation (McMillan & Schumacher, 1993) are not considered to be major threats, although comments about these areas were included in the field notes throughout the study and were offered whenever relevant in the thesis. The second point which should be considered is the opinion that "the purpose of case study is not to represent the world, but to represent the case" (Stake, 1994, p. 245). This issue of representation is frequently reported in the literature as a threat to external validity (e.g., Burton, 2000; McMillan & Schumacher, 1993; Yin, 1989). The same strategy for reducing threats to reliability as listed above—a careful documentation of the study—addresses the threat to external validity by enhancing the degree to which the findings of this study can be generalized or compared to other cases in the past, present, and future.

### 3.7 Summary

This chapter has presented this study's research design, including the frameworks which guide the data collection and systemic functional linguistic analysis. It has also described in detail the sites where the data were collected and the participants whose interactions and discourse are the focus of discussion over the next four chapters as an attempt is made to respond to the following research questions:

1. How do the teachers and students develop causal explanations and their relevant taxonomies through classroom interactions?
2. What are the causal discourse features which the students in the four contexts use to construct causal explanations?

Chapter 4 examines these two questions in Mrs. Sinclair's mainstream primary science class as the participants investigate the topic of magnetism. Chapter 5 looks at discourse around the same science topic by Mrs. Montgomery's ESL students. Chapter 6 discusses Mr. Peterson's high school mainstream class as the participants there address the subject of matter, and Chapter 7 explores Ms. Armstrong's ESL science class on the same broad topic as Mr. Peterson's class. Chapter 8 brings the four contexts together to respond directly to the research questions.

# CHAPTER 4: MRS. SINCLAIR'S PRIMARY SCIENCE CLASS

## 4.0 An overview of the chapter

Chapter 4 offers a detailed look at how the participants in Mrs. Sinclair's grade one/ two class learned about magnetism. As discussed in Chapter 2, the construction of field in science involves renaming, redefining, and reclassifying common-sense things to create technical, uncommon-sense taxonomies as well as the sequenced and reasoned arguments which draw on these taxonomies. The discussion of Mrs. Sinclair's magnet unit, therefore, emphasizes these two types of patterning which occur in the discourse, and asks the following research questions:

1. How do Mrs. Sinclair and her students develop causal explanations and their relevant taxonomies through the classroom interactions?
2. What are the causal discourse features being used by Mrs. Sinclair's students to construct oral causal explanations?

The first section of the chapter describes the general format of Mrs. Sinclair's magnet unit. Section 4.2 offers a detailed look at the first twenty minutes of the unit, during which time Mrs. Sinclair introduced the target vocabulary and told the students what they were about to do. Section 4.3 focuses on the twelve experiments which these students did, presenting the language the participants used to construct their understanding of magnetism. Section 4.4 focuses on four technical terms—*attract, repel, north pole* and *south pole*—and discusses how these four key terms were built up through the unit. These terms are considered key terms because they are central to the main generalizations being made in the unit.

It is important to note that Mrs. Sinclair's decision to have the students rotate through the different stations set up around the classroom made it difficult for her to bring the students together to discuss the experiments they were doing and to make broad generalizations about magnetism from the individual experiences of the students.

Section 4.5 examines the extended discourse which the students produced in the final question-and-answer period to explain their understanding of magnets. The final section offers a summary of the chapter.

## 4.1 Mrs. Sinclair's magnet unit

According to Mrs. Sinclair, the magnet unit was not typical of her usual science lessons; she considered the unit to be "a little bit different from the structured type of teaching." She said she enjoyed using the unit because it gave her students the opportunity to work with partners, to have fun, and to be responsible:

> ... they work in partners and... it's kind of fun when I put the onus on them and explain what they're going to do and they know that usually within a certain period they're going to be working at one station. It's fun for them and they know after they've finished... that particular experiment... that they can do other things of choice too. So it's different for them. (Interview with teacher)

Mrs. Sinclair further stated that no other science unit she has offers the same kinds of opportunities for students to engage in this type of hands-on, discovery learning. The plan for Mrs. Sinclair's magnet unit is shown in Table 4.1.

**Table 4.1: Mrs. Sinclair's plan for the magnet unit**

| | Date | Tasks | Areas or stations used |
|---|---|---|---|
| Day 1 | Monday, December 4, 2000 | introduction<br>one experiment | whole-class area<br>1, 3, 5, 7, 9, 11, 12 |
| Day 2 | Tuesday, December 5, 2000 | one experiment | 1, 2, 4, 6, 8, 10, 12 |
| Day 3 | Friday, December 8, 2000 | one experiment | 1, 2, 3, 5, 7, 9, 11 |
| Day 4 | Monday, December 11, 2000 | two experiments | 2, 3, 4, 6, 8, 10, 12<br>1, 3, 4, 5, 7, 9, 11 |
| Day 5 | Tuesday, December 12, 2000 | two experiments | 2, 4, 5, 6, 8, 10, 12<br>1, 3, 5, 6, 7, 9, 11 |
| Day 6 | Friday, December 15, 2000 | one experiment | 2, 4, 6, 7, 8, 10, 12 |
| Day 7 | Monday, December 18, 2000 | two experiments | 1, 3, 5, 7, 8, 9, 11<br>2, 4, 6, 8, 9, 10, 12 |
| Day 8 | Tuesday, December 19, 2000 | two experiments | 1, 3, 5, 7, 9, 10, 11<br>2, 4, 6, 8, 10, 11, 12 |
| Day 9 | Friday, December 20, 2000 | questions and answers | whole-class area |
| | (Wednesday, January 10, 2001) | (written test) | (students' desks) |

Mrs. Sinclair introduced the unit, the scientific method, and specific vocabulary items to the students as they sat cross-legged on the floor at the front of the room. This was the teacher's only formal, whole-class instructional time for the unit until the final question-and-answer period on Day 9. After the introduction, she assembled the pairs and assigned them to the stations that they would begin at. On Day 1, the students completed one station, and over the next seven sessions, the pairs rotated to the next station when the teacher instructed them to do so, with those finishing Station 12 moving to Station 1. The students were required to read the instructions at the station they were working at, carry out those instructions (i.e., do the experiment), and complete the task as described in their magnet booklets. Both Mrs. Sinclair and the researcher helped the students with any difficulties they had and occasionally asked questions about the experiments. When the students finished their experiments, they took a book to read and sat at their desks until they were invited by Mrs. Sinclair to begin the next task. The magnet unit extended over three weeks, nine school days, excluding the written review test which was administered in the following month and which is not discussed in this paper. Except for the final class period, which was used for the whole-class question-and-answer discussion, the students completed either one or two experiments per day, as Table 4.1 indicates.

Each of the twelve stations asked the students a specific question which was written at the beginning of the instruction sheet posted at that station (for the full station instructions, see Appendix 1). These questions, listed below in Table 4.2, captured the essence of what the students were examining. The language of the questions ranged from the use of everyday processes and participants ("pick up," "thing") to the common causal process *make* and the less common process *suspend,* to fairly complex, more abstract participants such as *the invisible forces of magnetism.* As the students worked through these stations, they completed their magnet booklets (Appendix 2). The questions for Stations Three, Four, Five, and Twelve appeared in the students' booklets, but generally, the language in the booklets was minimal, with the predictions, observations, and conclusions typically presented as sentence completions or fill in the blanks.

**Table 4.2: The questions at the stations**

| Station | Main question posed on the station instructions |
|---|---|
| One | Which things will a magnet pick up? |
| Two | How can we show the invisible force of magnets is real? |
| Three | Which of these magnets will pick up the most paper clips? |
| Four | Which of these magnets will pull a paper clip from the greatest distance? |
| Five | Which things will the force [of] magnetism pass through? |
| Six | How can you use a magnet to make a magnet? |
| Seven | How can you make a compass by magnetizing a needle? |
| Eight | How can we make the invisible forces of magnetism visible? |
| Nine | Where are the strongest parts on a bar magnet? |
| Ten | What happens when you cut a magnet in half? |
| Eleven | What can you find out about the poles of a magnet? |
| Twelve | How many magnetic marbles can you suspend in a chain? |

## 4.2 Constructing knowledge in Mrs. Sinclair's class

On the first day of the unit, Mrs. Sinclair invited the students to sit cross-legged on the carpet at the front of the room so that she could talk with them about the experiments they would be doing. There were two main tasks she undertook in this 18- to 20-minute teacher-fronted part of the lesson. The first was to tell them the basic sequence they would follow to carry out their experiments, and the second was to build up technicality by defining the terms she considered to be the key vocabulary items, ten terms which she had printed on the blackboard.

Mrs. Sinclair began by showing the students the little hand-made "magnet booklets" in which they would be writing their results, drawing their diagrams, and stating their conclusions (see Appendix 2). After a short discussion about where and how the students would put their names on the title page, she started the teacher-fronted instructional part of the lesson in which she hoped to inform them about their task and to construct appropriate meanings for the words she had written on the board.

### 4.2.1 Sequencing the unit

Within the 18- to 20-minute time period which introduced the magnet unit and its language, Mrs. Sinclair outlined the task ten times, attributing three distinct functions and linguistic "genres" to the ten sets of instructions (see Table 4.3).

There is a stark contrast between the set of instructions which the teacher used first and the instructions she used on occasions two and three, not only as a result of the genre and mood used, but because of the consistency and clarity of the language. The set of instructions she used on occasions two and three, constructed in the imperative and consistently employing the modal *will,* is clear and leaves little doubt as to what the students are supposed to do:

> You'll go to one station today. Each group. And I will tell you where to go at the station. You will write your names. You'll go to the station... and you'll read what it says on the chart that is stuck down there. Make sure you always keep it there... then you'll do exactly as it says. When you have... finished reading you will look at your magnet book and find the station that you need to be on and do what it says. When you have finished everything... you'll put it back in the box and make sure your names are on this and then you'll return to your seats and read a book or finish off whatever you have to do.

This set of instructions has the primary function of telling students what they will do, with little room for confusion.

**Table 4.3: Functions of the teacher's unit instructions**

| Task instructions | Function of instructions | "Genre" used | Language example |
|---|---|---|---|
| Occasion 1 | 1) overview of basic instructions<br>2) introduction of two terms from board:<br>• stations (implicit)<br>• conclusion (explicit) | primarily narrative, using the present continuous | I'm going to read this chart what it says first... I'm not going to take anything out of the box until I read it. And then... I'm going to start putting my answers in here. |
| Occasions 2, 3 | giving instructions | instructions in imperative, using the modal *will* | You will write your names. you'll go to the station... and you'll read what it says on the chart that is stuck down there. |
| Occasions 4 – 10 | checking student comprehension of task | questions and answers | T: What is the first thing that you are going to do?<br>S: Write your name on the line?<br>T: Correct. |

Her initial set of instructions, on the other hand, comes across as being much less direct and much more storylike. It is also more confusing, primarily because of its difficulties with pronoun deixis (the locational deixis was clarified through gestures). Whereas *I* begins as a referent for the teacher and *you* refers to the specific pair of students with *we* referring to the collective group at station one, *I* quickly shifts to become the referent for the student. Then, promptly, with no more warning than a slight pause, the *I* shifts back to refer to the teacher and the *you* once again becomes the referent for the student. The students must follow these shifts to follow the instructions:

> Okay... now let's say for instance I said Brian and Gary would be pairs. I don't think they are though here but that's beside the point. Um... and I said okay you two, you go to station one. Now if we look on this paper up here station one it says up here. It says attracted to magnet. Well you know you go over there and you say I'm going to read that chart what it says first... I'm not going to take anything out of the box until I read it. And then... I'm going to start putting my answers in here. And oh yes at station one there happens to be a word list to help me out with some of these things that I have to... I'm not going to tell you what to do yet. You have to read it. Okay so you have to put your answers right in there. Nice and neatly. And then there's a word that says oh... it's this word right here.

Fortunately, this set of instructions has a dual function, and the second purpose—that of introducing vocabulary to define—is explicitly and easily put forward to keep the lesson moving smoothly.

### 4.2.2 Building technicality: Renaming, redefining, and reclassifying

Before beginning her talk with the students, Mrs. Sinclair wrote on the blackboard the words she considered to be the key vocabulary items:

| | | | | |
|---|---|---|---|---|
| stations | prediction | observation | south pole | repel |
| diagram | conclusion | north pole | attract | suspend |

An examination of the students' attempts at defining these terms reveals that they used a variety of resources to construct the value in token-value relationships. A total of 37 definition attempts occurred during this introduction to the unit, 22 involving participant tokens and 15 defining processes, as illustrated in Table 4.4.

**Table 4.4: Forms of the students' definitions**

| Token participants | Value | No. of times (/21) |
|---|---|---|
| conclusion | what happens after you do it | 1 |
| purpose | what we want to learn | 1 |
| observation | what you think... | 2 |
| diagram | something done with... | 1 |
| diagram | something like a... | 2 |
| observation | something people say | 1 |
| diagram | a... | 8 |
| diagram | a kind of... | 1 |
| diagram | to help you *(infinitive)* | 2 |
| observation | looking..., guessing... *(present participle)* | 2 |
| **Carrier participants** | **Attribute** | **No. of times (/1)** |
| north pole | full of snow | 1 |
| **Token processes** | **Value** | **No. of times (/15)** |
| attract | when girls want to attract boys | 1 |
| attract | attract a boy *(stem)* | 1 |
| repel | unpull, de-pull *(stem)* | 2 |
| suspend | drop down *(stem)* | 1 |
| suspend | like you got rid of something | 1 |
| attract | like you're attracting something | 1 |
| attract | attracting boys *(present participle)* | 1 |
| attract | pulling things together *(present participle)* | 1 |
| suspend | spending money, writing things down, talking to someone *(present participle)* | 3 |
| suspend | not spending *(negative + present participle)* | 1 |
| suspend | things falling *(participant + present participle)* | 1 |
| suspend | something better | 1 |

When guessing at unfamiliar terms, the students tended to draw from what was familiar or observable. In trying to define *attract*, for example, both Celeste and Mandy insisted that the process revolved around female-male relationships:

Celeste: Attract a boy. I know what it is. Attract a boy.
Mandy: Like um it's uh when when girls ah... wants to attract boys.

Mrs. Sinclair confirmed the connection between their definition, one which is obviously more familiar to these girls, and the definition which suits their scientific purpose better, *pulling things together*, which was offered soon after by Bob. The teacher said:

> Yeah. Pull things together. You see in a way Mandy you're right... you know because when you say that a girl is attracting a boy you're pulling two people together. But when you attract in like in magnetism you pull things together.

The teacher then tried to use the newly defined *attract* to elicit the meaning of *repel,* setting up the two as opposites. She stifled laughter at the unexpected response which showed how some of the students were using their evolving linguistic knowledge:

| | |
|---|---|
| Teacher: | This means pull together. What does this one mean. |
| Keith: | Unpull. |
| Student: | De-pull. |

Mrs. Sinclair had set up the two terms as opposites, and the students considered negatives and positives to be opposites. The use of the negative to imply this type of opposition surfaces again as the students work on the rule of magnetism at Station Eleven.

In a manner similar to the above use of morphological affixes to help define words, the students in one obvious case attempted to define a word based on its sound, one which reminded them of a familiar word:

| | |
|---|---|
| Teacher: | What does suspend mean? |
| Stanley: | Spending money. |
| Teacher: | No not spend. Suspend. |

More than one student made connections between *spend* and *suspend* based on the sounds of the two words and the morphological similarity the students assumed the words had.

Mrs. Sinclair ran into problems helping the students associate the less familiar word *diagram* with the more familiar term *picture* by using observable items in the classroom. She began by requesting a definition which would fit a pattern of *X is another way of saying Y,* yet she soon offered an example suggesting a semantic relation of *X is a kind of Y.* She drew on the blackboard an item which fit the "X" position of the latter pattern, or in other words, she drew a *type* of diagram (this became obvious when she later pointed to a picture on the wall as another diagram). What was immediately reflected in the students' responses was the effort to label the "X," expecting that by doing this, they would define *diagram:*

| | |
|---|---|
| Teacher: | Explain to me what a diagram is please. |
| Gary: | I know. |
| Teacher: | Gary? |
| Gary: | Is it... it's something done with a display. |

| | |
|---|---|
| Teacher: | Nope. Good try. Elly? |
| Elly: | Um something like a (xx) that's on the blackboard? |
| Teacher: | Yeah okay. You're on the right track. I see. I'll put a diagram on the board. **What is it?** |
| Student: | **It's an elevator.** |
| Student: | **A kind of map.** |
| Teacher: | It could be a map... but it's more like a... a a a a |
| Bob: | To help you? |
| Teacher: | a a Bob? You want to give it a try? |
| Student: | **A map?** |
| Bob: | Um it's something like um a helper? |
| Teacher: | Okay. |
| Student: | What about that... |
| Teacher: | This could be a diagram. *(She points to a picture on the wall.)* |
| Student: | Uh it's a picture. |
| Student: | A drawing. |

*(Four turns pass of students repeating this.)*

| | |
|---|---|
| Teacher: | It's a picture of what you have done. All scientists usually draw diagrams. A picture is a drawing of what they do. |

In order to define *diagram,* the students needed to determine whether the picture on the board represented the definition itself or whether it was just one example of many *diagrams.* Mrs. Sinclair's strategy finally succeeded when she chose an "X" which would work to her satisfaction in both patterns; in other words, her choice of *picture* to fill the position of "X" worked to her satisfaction in both the pattern of *X is another way of saying Y* and the pattern of *X is a kind of Y.* All parties seemed okay with this, in spite of the differences between *picture* and *diagram* as the terms may be used in science.

In the time allotted to defining the terms listed on the board, the students correctly guessed the meanings of *conclusion, attract, repel,* and *diagram.* The definition of *station* was embedded in the initial set of instructions and would be reinforced in subsequent sets as well as throughout the unit itself. *Observation* was unfamiliar to the students and was finally defined by the teacher, as was *suspend. Prediction* was embedded in the discussion of the scientific method; Mrs. Sinclair defined it quickly by saying, "you figure out what you know, what kind of answer you think you're going to come up with." The terms *north pole* and *south pole* were not defined in a token and value relationship, but instead phrased as carrier and attribute, with the attribute given observable characteristics for students to look for. With regards to *north pole,* Mrs. Sinclair stated, "I will just say that the north pole I think is the side which is gray." She followed this with "south pole is red." These observable characteristics, unlike a student's offering of the attribute as "full of snow," referred directly to the colors painted on the poles of the magnets they would be using at the stations. The teacher's choice of attributes served to reinforce the idea that the north pole which the teacher was referring to was not the one that the students associated with the upcoming holiday season.

It should be noted that out of the four terms which the students would need most to articulate their understanding of magnetism—*attract, repel, north pole,* and *south pole*—the most time was spent on *attract,* which was the only concept of the four that was initially familiar to the students. The definition for *repel* was based on that of *attract* and given as "push apart" (repeated twice together before going on to the next word), and the north and south poles were given visible attributes only, as described above. There was no effort to reinforce these terms at this time. (A fuller discussion of the treatment of these four terms is given in section 4.4.) As soon as *suspend* was defined as *hang* by the teacher, the second set of instructions was given (from Table 4.3, occasions 2 and 3, followed by the other occasions as each pair was given their booklets) and soon all students were at their stations working on their experiments. No reasoning or explaining of magnetism was carried out during this introductory session.

### 4.3 Carrying out the experiments

Each station had a set of instructions which Mrs. Sinclair expected the students to read prior to beginning the experiment. Her instructions as she introduced the unit to them emphasized this. Moreover, throughout the experiments she frequently reminded them to read the instructions:

> Okay now you're going to have to read the words here... Read for us Gary. (Teacher to Gary and Eddy, Station 1)
> Okay read it. (Teacher to Elly and Celeste, Station 1)
> The first thing you do is read. (Teacher to Billy and Peter, Station 3)

> Did you read it and find what it says here? Because you have to read before everything you do. (Teacher to Bob and Brian, Station 5)
> Read first before you do anything else because you don't know what you're doing. (Teacher to Mandy and Stanley, Station 7)
> Remember you need to read it first. You got to read it to me first. (Teacher to Shelly and Keith, Station 7)
> You have to read it out loud together. (Teacher to Cathy and Sam, Station 10)

This emphasis suggested that in the teacher's view, reading was the key language focus of the unit. If students could read the instructions, they would "pick up" the language and conceptual understanding as they progressed through the unit. This idea was supported by comments that the teacher made during a later interview as she reflected on the way she taught the unit:

> The actual particular stations are I find quite easy to read. There are a few that require a bit of help but generally speaking the brighter students can pick this up very easily and go on their own.... *(A little later in the interview she continues.)* but yeah they pick it up as they go along but it does require a little bit of teaching, too... especially with some slower students that I've had this year.

She acknowledged that some of the students in this class needed help understanding the task at hand, a situation made obvious by frequent cries of "I don't get this" and "This doesn't make sense." Not only did it appear that some students had difficulty understanding the written instructions, it seems evident that in general, they were also not "picking up" and using the science language presented in many of the station instructions.

### 4.3.1 Trouble with technicalizing

One of the most noticeable ways that the students' language differed from the target science language was in the use of processes for describing what magnets "do." As Table 4.5 shows, the students used 64 different processes, and out of 537 occasions where they talked about attraction, *work* was the most common process they used to describe what was happening (129 times; 24.02%), followed by *attract* (78; 14.53%), and *stick* (77; 13.34%). Some of the students chose to use mental processes such as *want* (4;.75%) and *like* (17; 3.17%), giving human qualities to the participant subject. Shelly, for example, showed her lack of confidence in the target science process *repel* (18; 3.35%) by consistently stating that the same two ends of a magnet repelled because they didn't like each other:

## Table 4.5: Processes used to describe *attract* across the twelve stations

| | Station number | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Process** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **Total (/547)** |
| attach | | | | 1 | | | | | | 1 | 1 | 1 | 4 |
| attract* | 39 | 11 | 2 | | | 1 | | | 2 | 11 | 12 | | *78 |
| be | 1 | | | | | | | | | | | | 1 |
| bounce | | 2 | | | | | | | | | | | 2 |
| carry | | | | | | | | | 1 | | | | 1 |
| click together | | 1 | | | | | | | | | | | 1 |
| come back up | | 1 | | | | | | | | | | | 1 |
| come in | | | | 1 | | | | | | | | | 1 |
| come together | | 1 | | | | | | | | | | | 1 |
| come up | | | | | | | | 1 | | | | | 1 |
| do | | 1 | | 1 | 4 | | 1 | 1 | | 1 | | | 9 |
| fall* | | | | | | | | | | 1 | | | *1 |
| float | | 3 | | | 1 | | | | | | | | 4 |
| get | | | 2 | | | | | | 1 | | | 1 | 4 |
| get past | | 1 | | | | | | | | | | | 1 |
| get through | | | | | | | | | | | | | 1 |
| give | | | 1 | | | | | | | | | | 1 |
| go | 1 | 1 | | 2 | 4 | | 1 | 3 | 1 | | | | 13 |
| go apart | | | | | | | | | | | 1 | | 1 |
| go around | | | | | | | 1 | | | | | | 1 |
| go crazy | | | | | | | | 1 | | | | | 1 |
| go down* | | 1 | | 1 | | | | | | | | | *2 |
| go through | | | | | 11 | | | | | | | | 11 |
| go together | | | | | | | | | | | 3 | | 3 |
| grab | | | 1 | | | | | | | | 1 | | 2 |
| hang | | | | | | | | | 2 | | | | 2 |
| hold* | | | 10 | | 3 | | | | | 6 | | 4 | *23 |
| hold on | 1 | | | | | | | | | | 1 | | 2 |
| hold up | | 2 | | | | | | | | | | | 2 |
| keep apart* | | 1 | | | | | | | | | | | *1 |
| keep trying to... | | | | | | | | | 1 | | | | 1 |
| like | 2 | 2 | | | | | | | | | | | 4 |
| like each other | | 9 | | 1 | | | | | | | 1 | | 11 |
| like to... | 1 | | 1 | | | | | | | | | | 2 |
| make (non-cause) | | | 1 | | | | | | | | | | 1 |
| move* | | | | | | | 3 | | | | | | *3 |
| pass | | | | | 2 | | | | | | | | 2 |
| pass through* | | | | | 4 | | 1 | | | | | | *5 |
| pick up* | 4 | | 14 | | | 3 | | 1 | 3 | 8 | | | *33 |
| pull* | | | 1 | 1 | | | | | | | 1 | | *3 |
| pull apart | | | | | | | | | | | 1 | | 1 |
| pull down | | 2 | | | | | | | | | | | 1 |
| pull together* | | | | | | | | | | 2 | 7 | | *9 |
| push | | 4 | | | | | | | | | 3 | | 7 |
| push apart | | | | | | | | | | | 25 | | 25 |
| push away | | | | | | | | | | | 1 | | 1 |
| push together | | | | | | | | | | | 3 | | 3 |
| repel* | | 13 | | | | | | | | 1 | 4 | | *18 |
| stand up | | 1 | | | | | | | | | | | 1 |
| start towards | | | | | | | 1 | | | | | | 1 |
| stay | | 2 | 1 | | 1 | | | | | | | 3 | 7 |
| stay together* | | | | | | | | | | 1 | 1 | 1 | *2 |
| stay up | | | | | 1 | | | | | | | | 1 |
| stick | 10 | 12 | 6 | 1 | 16 | 1 | 3 | 4 | 2 | 7 | 14 | 1 | 77 |
| sticks through | | | | | 1 | | | | | | | | 1 |
| stop | | 1 | | | | | | | | | | | 1 |
| take | 1 | | 2 | | | | | | | | | | 3 |
| touch* | | 1 | | | | | | | | | | | *1 |
| turn* | | | | | | | 1 | | | | | | *1 |
| undo | | | | | | | | | | | 1 | | 1 |
| unstick | | | | | | | | | | | 1 | | 1 |
| walk | 1 | | | | | | | | | | | | 1 |
| wants to... | 1 | | | | 2 | | 1 | | | | | | 4 |
| work | 55 | 3 | | 2 | 18 | 13 | 11 | 1 | 2 | 8 | 2 | 14 | 129 |

Items with an * indicate processes which appeared in the station instructions or magnet booklets.

| | |
|---|---|
| Researcher: | And what's keeping these two apart now? |
| Shelly: | Each other. Because they're going to repel because they don't like each other. |
| Researcher: | Mm-hmm? They're repelling because they're the same side of the magnet right? |
| Shelly: | And when they're the same side of the magnet they don't like each other so they repel. |

Other processes associated with animate participants were *grab* (2; .37%), *walk* (1; .19%), *carry* (1; .19%), and *stand up* (1; .19%), but whereas *grab* and *carry* referred to the magnet as the actor, the other processes were carried out by the items under the influence of the magnet. With the magnet near, the item "was walking a minute ago" (Brian, Station One) or "it's standing up" (Eddy, Station Two). This idea that the items somehow had the ability to "do" things surfaced clearly in a comment at Station Five, where Gary was holding a magnet above a paper clip which was anchored by string to a heavy block of wood:

Gary: It'll stay up by itself. Watch. Magnetism. Watch.

Although Gary acknowledges that magnetism is playing a role in what he is observing and uses the term when he talks, his language asserts that the paper clip somehow has the ability to stay up by itself.

**Table 4.6: The use of *attract* by students at Station One**

| Form of *attract* | Example sentence | No. of times (/39) |
|---|---|---|
| passive, no agent | These **are attracted.** | 10 |
| passive with *to* | The key **is** not **attracted to** it. | 4 |
| active, magnet as agent | A magnet **attracts** things made of metal. | 2 |
| *active, item as agent | This cork didn't **attract.** | 18 |
| *active with *to* | A special kind of metal **attracts to** the magnet. | 5 |

Items marked with an * indicate incorrect construction.

When *attract* was used, as it was on 78 occasions, it was not always used correctly. Table 4.6 reveals how *attract* was used at Station One in a variety of constructions, both active and passive, with and without agents, and frequently with the wrong agent. As seen in Table 4.6, out of the 39 sentences which use the word *attract* at Station One, 23 (58.97%; marked with an asterisk) were constructed with the item being tested given the power or agency to do the attracting. The students appeared to be using this process in the same way as they would use *work* or *stick;* in other words, it seems as though they may have been simply inserting the more scientific word into the place where they would more confidently use a process from their everyday lexicon. The following examples show this (the sentences marked with an X show incorrect meaning construction in that the item is not what is doing the attracting):

| | |
|---|---|
| Mandy: | Pennies won't stick. |
| Shelly: | Penny's not working. |
| Bob: | Pennies don't work. |
| Elly: | X Pennies don't attract. |
| Elly: | Money. It'll work. |
| Peter: | X The money doesn't attract. |

Yet when considering the scientific concept of magnetism, there are restrictions on the types of actors which can appear:

| | |
|---|---|
| Pennies<br>actor | don't work.<br>material process |
| Pennies<br>actor | won't stick.<br>material process |
| X The money<br>actor | doesn't attract.<br>material process |

Whereas in everyday understandings, pennies may not *work* with magnets or may not *stick* to magnets—and magnetism remains the unstated or implicit force which controls the things that happen—within the scientific concept of magnetism, only magnets or magnetized items have the power to attract or not attract, and therefore pennies (or any other item tested by the students) cannot be the actor in the construction. Teaching magnetism, and teaching the term *attract,* involves introducing the structure of meaning associated with the scientific concept of magnetism, and within this structure of meaning, the process *attract* must involve an actor which explicitly states what is doing the attracting.

This substitution of everyday processes for the more scientific terms without considering what types of participants the process allows is supported further by Brian's definition of *attract,* which he gave to his partner as they were testing the items:

| | |
|---|---|
| Brian: | Attracted. That means that that *(the bottle cap)* holds on to the magnet. You see if I put it *(the bottle cap)* there it *(the bottle cap)* will work. You think if I put this *(the piece of wood)* right here it *(the piece of wood)* wouldn't work? |

Brian's definition, along with the many examples of the processes in the data, suggested that the students may not have understood the role which the subject or actor plays in a construction with *attract.* Frequently the students' language suggested that they considered words like *stick* and *work* to be interchangeable with *attract,* that *attract* is simply the scientific word for *stick,* which it is not.

The participants that the students chose to use to talk about what they were observing were usually either labels for the specific items the students were working with or the exophoric terms which replaced them, such as *it, this, they, that, yours,* and *most of them.* The following excerpt from Sam at Station Two shows how dependent on the context some of the discourse was:

| | |
|---|---|
| Sam: | It's because that has no this and that means the magnet in the thing... Because if this like this *(he turns the magnet over so there is attraction)* would even break. And then you'd have pieces. |

Moreover, rather than using *north* or *south* consistently, the students used participants such as *bottom parts* or *bottom one, silver, red, white, each other, same side, the opposite, the other,* and *one*, all heavily dependent on the observable context; *silver, red,* and *white* refer to the colors which indicate poles on the various magnets that the students worked with. This suggests that at the stations, the language was heavily context-dependent and associated with the students doing the experiments. Yet even when the students were away from the stations, their language remained tied to the observable contexts, a point that will be brought up again later. With the exception of Station Eleven, where all the questions in the written texts concerned the north and south poles, the students in most cases referred to the poles by name only when prompted to do so by the researcher, and even in these exchanges, they appeared to favor the observable characteristics of the magnets over the more abstract concepts of *north* and *south.* Furthermore, as the following conversation suggests, the students appeared to be unsure of these concepts and were more comfortable with *north* and *south* being geographical poles in spite of prompting by the researcher:

| | |
|---|---|
| Researcher: | What kinds of poles attract? |
| Gary: | The |
| Researcher: | You've got it here. |
| Gary: | The magnet poles of course! |

| | |
|---|---|
| Researcher: | Well we've got a north pole and a south pole. Right? So the different poles... opposite poles... attract. If it's two [south poles |
| Gary: | [Oh because it you said it um like different. It's like south and north... they're like... like in the world there's two south... south pole and north pole. |
| Eddy: | Wait wait wait maybe it's standing up because... the bottom one is facing the white and that one is... oh yeah that one is facing and this one's facing red. |
| Researcher: | So this pole... and this pole... are? |
| Gary: | South and north! |
| Eddy: | South and north! |

Although Gary was trying to connect the concept of the magnetic poles to geographic poles, Eddy's response was very much anchored in what was observable to him. In the end, they both responded using the target science terms, but their responses of "north and south" were incorrect based on which poles the researcher was indicating, suggesting that they were still uncertain about the terms and the concepts.

**Table 4.7: Science participants and their everyday replacements**

| Science word | Children's preference |
|---|---|
| north | silver *or* gray |
| south | red |
| pole | end *or* side |
| iron filings | sand |
| diagram | picture |

Table 4.7 lists the five "science" participants which either Mrs. Sinclair had introduced or which were used in the instructions to the experiments. It also shows the everyday terms which the students preferred, words which appeared to be based on what they could see or what they were more familiar with. When the students were engaged in the experiments, they tended to use these everyday words along with exophoric terms and labels for the items they were working with, usually specific participants ("this magnet," "these keys," "the red side"). At times, one student would report or speculate on the findings to his or her partner, and on these occasions, general participants would sometimes appear ("pennies don't

work," "it passes through plastic"). Moreover, often when Mrs. Sinclair turned the students' attention to the conclusions in their magnet booklets, the participants shifted from the specific to the general, as needed. At Station One, for example, after classifying items based on whether or not they were attracted to the magnets, the students were able to generalize that "magnets attracted things made of metal," although the first words of this conclusion were supplied in the magnet booklets.

### 4.3.2 Opportunities for reasoning

Rather than promoting explorations into *why* things happen, most of the experiments required the students to manipulate objects, observe what happens, and attempt guided generalizations for conclusions, all leading to an experiential understanding of the field. For example, several experiments required students to discover which magnet was the strongest and to justify their responses by describing what the magnet was able to do in order to be called the strongest (e.g., "because it pulled from the farthest"). During the experiments, the students frequently made comments about what they were seeing or directions to their partners on what they were, or should be, doing. The following excerpt from Station Two shows these types of comments:

| | |
|---|---|
| Mandy: | This is cool! Lookit! We're magic! |
| Stanley: | Watch this watch this watch this! Um... flip this over. Now try it... Put it in the same way. Now put it that way now. Wow! Lookit my magic! Wow! Lookit! |
| Mandy: | It's pushing! This is cool! |

This type of talk offers comments about what the students were seeing, but it does not go deeper into why the magnets are "pushing." To explain this Station Two phenomenon—rather than simply comment on it—the students needed to make connections to what they had done at other stations, most notably Station Eleven, and not all of them had done those experiments successfully. Because they had started at different stations, and because the teacher and researcher frequently needed to help them understand the procedures for carrying out the experiments, it appeared difficult to make connections or to elicit explanations regularly from all students. As Table 4.8 shows, there were limited examples of these attempts in the discourse of the experiments. Yet when these questions were asked, the response typically contained an effort by the student at cause-and-effect reasoning.

**Table 4.8: Teacher/researcher use of question probes**

| | Station numbers | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **Total** |
| teacher/researcher asking children *why* | 2 | 3 | 4 | 1 | 3 | 1 | 0 | 0 | 1 | 0 | 0 | 2 | 17 |
| teacher/researcher asking *what happens* | 0 | 9 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 7 | 7 | 5 | 31 |
| teacher/researcher making connections to other experiments | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |

These interactions between the teacher and the students worked to construct temporal and casual relations. For example, the following excerpt shows how the teacher used a *what happens* question to see if Keith understood that rubbing a nail two hundred times across a magnet caused it to become a magnet (Station Six):

Teacher: Normally what happens... is what? What would happen?
Keith: Uh it'll... pick up.
Teacher: That's correct.
Keith: It'll be a magnet.

Keith's response showed that he knew what the effect was of rubbing the nail on the magnet.

Often the teacher or researcher presented the framework for an *if*-clause or a *when*-clause by providing the first part of the construction:

Researcher: When you cut a magnet in half you make?
Brian: Two!... It... made... two. (Station Ten)

They also did this by turning a conditional sentence into an either/or question:

Teacher: I think if you cut a magnet in half will it pick up or it won't pick up?
Celeste: It will.
Teacher: It will pick up?
Elly: It will.
Celeste: It would still be a magnet.

How the teacher or researcher phrased these questions depended on the station's target questions and the conclusions the student needed to arrive at, yet these types of interactions were one way that brief causal explanations were constructed without the students themselves articulating the linguistic features usually associated with cause.

Table 4.9 offers a list of the students' temporal and causal relations which were either co-constructed with the teacher or researcher (marked by parentheses), or constructed independently by the student. As Table 4.9 indicates, out of 168 temporal and causal relations found in the discourse, the students constructed 123 (73.21%) independently and 45 (36.59%) with the teacher or researcher. Only 36 (21.43%) of the relations were temporal, using the *when*-clause adverbial of time. Of the 132 (78.57%) causal relations, ones using *because* were the most common (61; 46.21%), followed by ones with *so* (38; 28.79%), and the *if* conjunction, or adverbial of condition (33; 25%).

The high frequency of causal conjunctions over temporal ones in these constructions is also reflected in the list of temporal and causal features used by the students across the twelve experiments, as shown in Table 4.10. The popularity of these conjunctions suggests that the students were relying on the more congruent forms of causal discourse. Even the temporal conjunctions were at times used in constructions which promoted causal interpretations. For example, the word *now,* usually used to build a temporal meaning, took on a causal interpretation in the following example:

Cathy: It's moving north. Yeah. Look at that one there.
Sam: Hey that worked.... Now it's south.

Sam's use of *now* links the two clauses temporally, yet his construction appears to suggest that the needle's turning south is evidence—and therefore reason to believe—that the needle had been magnetized and the experiment had worked.

This subtle suggestion of a causal link in temporal conjunctions also appeared in the students' constructions of *when*-clauses. Some of these simply related two clauses in time, as in "When we did it this was the strongest, one two and three" (Brian, Station Three). No causal interpretation can be made of this; the sentence does not suggest that doing the experiment will logically result in a particular magnet being the strongest. Yet these temporal-only constructions were not common; the students' *when*-clauses typically offered causal implications. When Stanley said "When you cut a magnet in half it still pulls together" (Station Ten), he was suggesting that cutting the magnet would result in a

**Table 4.9: The temporal and causal relations constructed at the twelve stations**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X because Y | 2 | 5 | 8 | 2 | 2 | 2 | | | 1 | 1 | 2 | 1 | 26 |
| X because not Y | | 4 | | | | | | | | | 1 | | 5 |
| not X because Y | | | | | | | 1 | | 1 | | | | 2 |
| not X because not Y | 1 | | | | | | | | | | | | 1 |
| X because... | 1 | 2 | | 2 | | | | | | 2 | | | 7 |
| X because X | | | | | | | | 1 | | | | | 1 |
| (X) because Y | | 7 | 4 | 1 | | | 1 | | | | | 1 | 14 |
| (X) because not Y | | | | | | | | | | | | 1 | 1 |
| (not X) because Y | 1 | | | | 3 | | | | | | | | 4 |
| X so Y | 3 | 1 | 6 | 4 | 2 | | 2 | 2 | 1 | 2 | | 2 | 25 |
| X so not Y | | 2 | | | | | 1 | | | | | | 3 |
| X so... | 2 | | | | | | | | | | | | 2 |
| not X so Y | | 2 | | | | | | 1 | 1 | | | 1 | 5 |
| not X so not Y | 1 | | | | | | | | | | | | 1 |
| (X) so X | | | | | | | | | | | 2 | | 2 |
| X if Y | 2 | 1 | | | | | | | | | | | 3 |
| if X, then Y | 1 | 3 | | | 3 | | | | | 3 | | 4 | 14 |
| if X, then not Y | 1 | | | | | | | | | | | | 1 |
| if X... | 1 | 1 | | | | | | | | | | | 2 |
| (if X), then Y | | 5 | | | | | | | | 1 | 4 | 1 | 11 |
| (if X), then not Y | | 1 | | | | | | | | | | | 1 |
| (if not X), then not Y | | | | | | | | | | | 1 | | 1 |
| when X, then Y | 1 | 5 | 4 | 1 | 1 | | 1 | | | 4 | 1 | 1 | 19 |
| when X, then not Y | | 3 | | | | | | | | | | | 3 |
| when X... | 2 | | | | | | | | | 1 | | | 3 |
| (when X), then Y | | 4 | | | | | | | | 2 | 1 | | 7 |
| (when X), then not Y | | 3 | | | | | | | | | 1 | | 4 |

Items in parentheses indicate another speaker.

## Table 4.10: Causal discourse features used across the twelve stations

| | Station numbers | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Language Features** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **Total** |
| **TIME conjunctions** | | | | | | | | | | | | | |
| and then | 1 | 2 | 1 | | | | 3 | | 2 | | 2 | 2 | 13 |
| then | 2 | | | 1 | 3 | | 1 | | | 1 | 1 | 1 | 10 |
| first | 1 | | | | | 1 | | | | | 1 | | 3 |
| now | | 3 | | | | | 1 | | | | 1 | | 5 |
| still | | | | | | | | | | 8 | | | 8 |
| once | | | | | | 1 | | | | | | | 1 |
| when… then… | 1+2* | 15 | 4 | 1 | 1 | | 1 | | | 6+1* | 3 | | 33+3* |
| **TIME processes** | | | | | | | | | | | | | |
| start | | | 1 | | | | | 1 | | | | | 2 |
| **TIME participants** | | | 3 | 4 | | | | | | 5 | | 9 | 21 |
| **PLACE circumstances** | 3 | 3 | | 2 | 9 | | 7 | 6 | 1 | 2 | 3 | 2 | 38 |
| **CAUSE conjunctions** | | | | | | | | | | | | | |
| because | 4+1* | 16+2* | 12 | 3+2* | 5 | 2 | 2 | 1 | 2 | 1+2* | 3 | 3 | 54+7* |
| so | 4+2* | 5 | 6 | 4 | 2 | | 3 | 3 | 2 | 2 | 2 | 3 | 34+2* |
| if… then… | 4+1* | 10+1* | | | 3 | | | | | 4 | 5 | 5 | 31+2* |
| do X and Y happens | | 1 | | | | | | | | 1 | | | 2 |
| do X or Y won't happen | | | | | 1 | | | | | | | | 1 |
| **CAUSE processes** | | | | | | | | | | | | | |
| make (X) | 2 | | | | 1 | 1 | 4 | | | 1 | | | 9 |
| make (X do Y) | | 2 | | | 2 | | | 1 | | | | | 6 |
| force | | 1 | | | | | | | | | 1 | | 2 |
| **CAUSE participants** | | | | | | | | | | | | | |
| What happens (is)... | | | | | | 1 | | | | | | | 1 |
| **CAUSE circumstances** | | | | | | | | | | | | | |
| for some reason | | | | | 1 | | | | | | | | 1 |
| **MEANS circumstances** | | | | | | | | | | | | | |
| by showing | | 3 | | | | | | | | | | | 3 |
| by this magnet | | | 3 | | | | | | | | | | 3 |
| by itself | | | | | 1 | | | | | | | | 1 |
| by magnetism | | | | | | | 1 | | | | | | 1 |
| with the magnet | | | | | | | | | 1 | | | | 1 |
| with water | | | | | 1 | | | | | | | | 1 |
| with this block of wood | | | | | 1 | | | | | | | | 1 |

Items marked with an * indicate aborted attempts at explaining (i.e., unfinished thoughts) continued ability to attract. The difference in the tense of these constructions was a good indicator of causality: Constructions using the past tense indicated a temporal-sequential meaning whereas those in the timeless present suggested causality and an effort by the student at generalization and rule-building.

Table 4.10 shows that the use of grammatical metaphor by these students throughout the twelve stations was very limited. Causal and temporal processes were rare, with *make* appearing most commonly in constructions such as the following:

| | |
|---|---|
| Shelly: | Don't try to make it touch! I'll show you how to do it. Just try making it like that. (Station Five) |
| Bob: | I've always been wondering how magnets work. What makes it work. (Station Two) |
| Brian: | I mean like cut this and then it'll make two sides. Cut one and it'll make two sides. (Station Ten) |

Circumstances of means, also rare, were sometimes prompted by the wording of the station instructions or the conclusions as they appeared in the magnet booklets. The passive voice was also uncommon throughout the twelve experiments. As discussed earlier, the passive was used with *attract* at Station One, but the only other examples occurred in infrequent examples of "it is called" and one effort by Shelly at Station Two when she described the two ring magnets by saying "they're re re repellinated."

While Table 4.10 offers an idea of the typical causal resources that the students used to construct causal meanings and accounts for the majority of the explanation attempts, it does not present the full list of strategies which they used to construct causal explanations. The data reveal examples where the students constructed causal connections without explicit linguistic markers from the teacher or the student. At Station Eight, for example, Mandy asked a question and answered it herself in a way which showed her understanding:

| | |
|---|---|
| Mandy: | Hey how come this magnet doesn't pick up that magnet?<br>It's not heavy enough. |

At Station Three, she observed that the paper clips she was working with were not adequate for helping her explain to the teacher what was happening. In her explanation attempt, the because is implied:

| | |
|---|---|
| Mandy: | What I did was... no these won't be good. They're all chained. |

At Station Five, Eddy explained why his effort at passing an item between the magnet and the paper clip failed:

| | |
|---|---|
| Eddy: | Oh do you know why? I touched it. We'll try again. |

A few turns later, Gary explained why the magnet was able to attract a paper clip through a piece of wood:

| | |
|---|---|
| Gary: | It's a strong one. It's too strong. That's why. |

At the same station, Keith explained to the teacher that his magnet wasn't able to attract the paper clip through the wood he had tested because the wood was too thick:

| | |
|---|---|
| Teacher: | Did it work Keith? |
| Keith: | No. |
| Teacher: | So what would— |
| Keith: | Too thick. |

The reasoning of these students is clear, despite the lack of any explicit causal language features beyond the use of *why* in their discourse.

At times, the students exhibited their understanding of magnetism through play and the language around this play. Mandy was particularly productive in this area, drawing other students' comments into her storytelling:

| | |
|---|---|
| Mandy: | And then they see this big guy and they say oh a monster! Ah a monster! You'll never get away! Because they're in there and they're going to grab you and… You can get us out! The magnetism went together too much and it was too much for the package. *(A short time passes as she continues playing with the magnets without talking.)* Then these guys got stuck together. |
| Elly: | They can't get stuck together. They're facing the wrong way. |
| Celeste: | They can't get them out. It's the law. It's like a locked cage. |
| Mandy: | Even if they are locked in there we'll get them out somehow. It's easy… or magnetism or something like that. |

The process which Mandy used in her play, such terms as *grab, went together,* and *got stuck together,* described the action she observed happening with the magnets. The participants she chose, with the exception of magnetism, reflected the story she was creating and added an animate quality: *big guy, monster, you, us,* and *these guys.* The effect provided the magnets with agency as they took on identities of "monsters" and "big guys" who grabbed and got other things out of the packages. This was continued by Elly, who by pointing out that Mandy was aligning the magnets with like poles together so that they "can't get stuck together," and Celeste, who commented that the package was like a locked cage when the wrong end of one magnet was used to try to lift the other magnet out.

Mandy used the term *magnetism* in her play, but it was not clear exactly what meaning she was giving it. Her first use of the term seemed to equate it with a force which could bring the two magnets together strongly enough to lift one magnet out of the plastic package used for storage: "The magnetism went together too much and it was too much for the package." She used the term again a few turns later, equating it with "easy," in the sense of *how* she could get the magnet out of the plastic package. A few turns later she used it again in her story:

| | |
|---|---|
| Mandy: | It does not hurt. It's like no and then these guys attached on. It's like magnetism's better! Whish whish whish. Put these on. These guys were holding on to the ground too tight. Then these guys got stuck together. Aaaagh! |

The use of *magnetism* here is not clear to the listener or the watcher of Mandy's story and no clarification is requested. Mandy seemed to have acquired the term, but did not demonstrate a scientific usage of it and instead played with the term as she did with the magnets.

Much of the feedback that Mrs. Sinclair offered the students was aimed at moving them towards the conclusions that they needed in order to complete the experiments in their magnet booklets and begin the next experiment or classroom event. To this end, she would ask the students what they would write, asking questions such as

- Can you figure out a conclusion already?
- So what will your conclusion be?

The teacher generally accepted the conclusions which the students offered, whether these indicated an understanding of the concept being considered or not, as the following exchange with Stanley illustrates. Stanley and his partner, Mandy, had just finished doing their experiment in which the two ring magnets are observed to be "floating" (Station Two). They were filling in the section of their magnet booklets which stated "You can show an invisible force is real by showing _______" when Mrs. Sinclair approached them:

| | |
|---|---|
| Teacher: | What was your conclusion? What did you find out? |
| Stanley: | By showing my diagram. |

| | |
|---|---|
| Teacher: | Yeah. Or by showing it in an experiment. |
| Stanley: | I'll say the diagram. |
| Teacher: | Isn't that nifty? *(Talking about the experiment.)* I just really got a bang out of this experiment. That was my favorite experiment. It's neat. |

Stanley wrote his answer, "a diagram," in his magnet booklet as his conclusion, as did Mandy.

Mrs. Sinclair not only asked students to state their conclusions and accepted what they offered, she often gave them the answer if they did not come to a conclusion themselves. Whereas in the example above, she gave Stanley a better response which he rejected in favor of his own ideas, she offered Brian a much longer answer at Station Eleven, where he had run into difficulty understanding what he was to do:

| | |
|---|---|
| Brian | Mrs. Sinclair? This doesn't make sense. It says... |
| Teacher | Okay? |
| Brian | one north pole. One south pole. |
| Teacher | Okay so that means one of these and one of these. These ones– We call these both south if you want. They push apart. These push apart right? But if you mix them what happens? What's the word? |
| Brian | Attract. |
| Teacher | They attract. That's right. So one north and one south pole attract. |
| Brian | So I just write "they attract"? |
| Teacher | Yeah. And then down below when it comes to the rule you can put either north and north poles attract or south and south poles att– no they don't attract. North and south poles attract? Right? |
| Brian | Yeah. |
| Teacher | But north and north poles repel or push apart. Or south and south poles repel. Right? |
| Brian: | Okay. |
| Teacher: | Okay? Good. |

Mrs. Sinclair gave Brian the response he needed for his magnet booklet, yet there is little discourse evidence that he understood what the rule was. His magnet booklet was also left incomplete, although he had written "they attract" in the appropriate space.

As sections 4.3.1 and 4.3.2 have attempted to show, the students in Mrs. Sinclair's class continued to use the language they brought initially to the unit, rather than adopting the technical language associated with the field of magnetism. They appeared to be uncertain about the target science language, using it sparingly and at times incorrectly. Although the students made generalizations about what was happening, changing specific participants into general ones when required to do so, they preferred to use their everyday taxonomy of terms which were based on observable participants and familiar processes, and this preference for congruency continued throughout the twelve stations and into the final question-and-answer discussion.

### 4.4 Tracking the construction of three key concepts

As discussed in section 4.2.2, Mrs. Sinclair spent time on the first day of the unit examining ten terms which she felt the students would need to understand before they could carry out the twelve experiments successfully. These words appeared in the written instructions posted at the stations and in the students' magnet booklets. It was also noted in that section that of the terms which were needed the most to discuss magnetism in science, the most time was spent on establishing a definition of *attract,* and less was spent on the other three terms, *repel, north pole,* and *south pole.* This section will revisit these terms with an aim to shed light on the students' preference for talking about the rule of magnetism in non-technical terms.

#### 4.4.1 Building up an understanding of *attract*

On the first day of the unit, Mrs. Sinclair asked the students what *attract* meant and prompted the following discussion:

| | |
|---|---|
| Teacher: | What does attract mean? Attract. Celeste? Attract... Come on Eddy. Think. |
| Celeste: | Attract a boy. I know what it is. Attract a boy. |
| Teacher: | Shh. Keith back up a little bit. Thank you. What does attract mean? |
| Student: | Uh I don't know. |
| Teacher: | Uh that's okay. Mandy? |
| Mandy: | Like um it's uh when when girls ah... wants to attract boys? |
| Teacher: | Well that's not quite—well it could be. It could be but what does attract itself mean? Brian? |
| Brian: | Like you're attracting something? |
| Teacher: | What does attract mean? You're using the same word. |

| | |
|---|---|
| Brian: | I don't know. |
| Mandy: | Attracting boys. |
| Student: | Um. |
| Mandy: | Attracting? |
| Student: | Attracting means? |
| Student: | Attracting? |
| Teacher: | No. |
| Bob: | I know it! |
| Teacher: | Bob? |
| Bob: | Um pulling things together? |
| Teacher: | Yeah. Pull things together. You see in a way Mandy you're right... you know because when you say that a girl is attracting a boy you're pulling two people together. But when you attract in like in magnetism you pull things together. |
| Stanley: | I know but I was I was going to say I was going to say like a magnet and a magnet and a piece of metal and a magnet attracts the piece of metal. |
| Teacher: | Sit down. Stanley. Yes Stanley. It could be. |
| Stanley: | I know. |

Mrs. Sinclair is doing two things here. On one level, she is giving students an idea of what constitutes an acceptable definition attempt. She does not accept Celeste's "attract a boy" and instead calls for quiet and repeats the question. She considers Mandy's definition somewhat more favorably in its *X is when Y* format, but focuses on the word *attract,* which both Celeste and Mandy have used in their definitions. She then rejects Brian's offer, reasoning that he is just repeating the same word, and suggesting that using the same word does not help to define it, a suggestion that is useful for all students but which appears not to be understood or accepted as yet another girl offers "attracting boys" as a definition and others continue to repeat the word.

The teacher's primary goal in eliciting a definition is to set up a translation between the technical term *attract* as it is used in science and the same term as the students already appear to understand it. She does this by appropriating the common-sense term which Bob has offered, *pull things together.* Yet rather than leaving the definition of the term as a token/value relation such as the one Bob has suggested:

| attract | means | pull together |
|---|---|---|
| token | rel:int | value |

Mrs. Sinclair further offered two reasonably parallel logical relations which use both the target term *attract* and the more common-sense term which could be used to define it:

Everyday: when you say that a girl is attracting a boy you're pulling two people together

Technical: when you attract in magnetism, you pull things together

The distinction then becomes not so much one of everyday versus technical *terms,* but of everyday versus technical *contexts,* which suggests that both words can be used in either context. In other words, the focus is not only on translating between *pull together* and *attract,* but on moving from using either of these two terms in everyday contexts to using either term when talking about the scientific context of magnetism. The initial construction of a reversible intensive relation allows for both terms to be equated, and the acceptance of everyday and technical terms in scientific contexts is further reinforced throughout Mrs. Sinclair's unit by her tolerance of the variety of terms which the students uttered as well as by the use of these terms in the written texts of the unit.

In the written instructions which appear at the stations, both the everyday term and the technical term are used, potentially reinforcing the acceptability of both terms for describing science. In fact, *attract* appears only six times in the instructions of the twelve stations, and five of these are at Station One:

Which things will a magnet pick up?

1. Sort the objects into two groups, those you think the magnet will attract, and those you think the magnet will not attract.
2. Test each object by bringing the magnet close to it. If the object is attracted to the magnet, write its name under that heading in your booklet. If the object is not attracted to the magnet, write its name under that heading in your booklet.
3. Put a star * in front of each object you predicted correctly.
4. What did you notice about the objects which were attracted to the magnet?
5. Put all the objects back together in the box.

The use of *attracted* and *not attracted* here matches the headings in the students' magnet books and therefore helps the students understand which objects to put under which heading. The use of *pick up* offers a translation between the non-technical and the technical. As noted in section 4.3.1 (Table 4.5), however, the students at Station One used eleven other words instead of *attract,* of which *work* was the most popular process used (55 out of 117;

47%), followed by *attract* (39; 33%) and *stick* (10; 8.5%). *Pick up* is used on four occasions (3.4%). This variety occurred despite the teacher's modeling of *attract,* which she used substantially more often than other processes when she talked with the students at this station (47 out of 62 occasions, or 75.8%; versus *work,* 12 or 19.4%; *pick up,* 2 or 3.2%; and *stick,* 1 or 1.6%).

It was also mentioned in section 4.3.1 that the students did not always use *attract* correctly, often substituting it directly into the clause in place of their everyday term and therefore attributing magnetic agency to a non-magnet actor. Although the teacher at times used *attract* in the same way, usually when repeating a student's comment, out of the 47 uses of *attract* by the teacher and researcher at Station One, 41 of these (87.23%) correctly modeled either the use of the passive (e.g., "Is that attracted?") or the active (e.g., "What kinds of things did the magnet attract?"). These findings suggest that even when the students attempted to use the target term, they were not attending to the teacher's modeling of the correct use of that term. Furthermore, there was little emphasis by the teacher on the students' correct use of the technical term.

The other occurrence of *attract* in the written instructions was at Station Eleven, where the term is used parenthetically after the final example of *pull together:*

> What can you find out about the poles of a magnet?
> 1. Put the south poles of the two magnets together. Observe what happens. Did the magnets pull together or push apart? Write your observations in your booklet.
> 2. Put the north poles of the two magnets together. Observe what happens. Did the magnets pull together or push apart? Write your observations in your booklet.
> 3. Put the north end of one magnet near the south pole of the other magnet. Observe what happens. Did the magnets pull together or push apart? Write your observations in your booklet.
> 4. See if you can figure out the rule for whether magnets will pull together (attract) or push apart (repel).

In the students' magnet booklets, the rule used *attract,* so the gloss in step four was useful for helping the students translate between the technical term and the everyday wording of *pull together,* a term which had been introduced by Bob and the teacher on the first day of the unit but which had been used only nine times throughout the twelve stations, seven of them in the station above. The position of *attract* as a parenthetical gloss (almost an afterthought by the writer) seems backwards, serving to play down the more technical term as a definition of *pull together,* which is the term which is more likely to be familiar to the reader. Reversing the order of these words—placing the everyday term in parentheses to help the students translate the more unfamiliar technical term—may offer a better strategy for emphasizing the appropriate science term. Its current parenthetical state further reinforces the idea that in the science context, either term is acceptable.

The concept of *attract* was also being constructed in the unit through experience as the students manipulated the magnets according to the written instructions. During the twelve experiments, the students felt, for example, the strong attraction of the wand magnets as bottle caps snapped onto them. They watched as the different magnets pulled the paper clips towards them. They saw how a paper clip tied to a string could be suspended in midair by a magnet held over it. All of these experiences aimed to build up the concept of *attract,* to show the students what the technical term meant and why everyday terms would not capture the same meaning. Yet without a discussion of how these experiences relate to the overall concept, the students may have been left to label the experiences separately and therefore did not learn as much about the concept of *attract* as the teacher had hoped. Moreover, the movement through the stations by the pairs of students did not present the best opportunities for these needed discussions to occur. For example, one pair of students began with Station Eleven and its rule-writing before building an understanding of the basic idea of *attract,* while another pair was required to apply that rule to explain what was occurring (Station Two) without having first been introduced to Station Eleven's rule. Mrs. Sinclair could not always discuss these experiences with the students because she was unable to be in two places at the same time. The movement through the stations, although useful in that it allowed all students to experience all the experiments without having to use a large quantity of materials, may have helped keep these experiences separate rather than combining them to construct a solid conceptual understanding of the technical term, *attract.*

### 4.4.2 Building up an understanding of *repel*

The technical term *repel* was defined on the first day of the unit. Mrs. Sinclair helped the students define *attract* and then used that definition to uncover the meaning of *repel:*

| | |
|---|---|
| Teacher: | What does repel mean then. If this means attract what does repel mean? Keith? |
| Keith: | Um what? |
| Teacher: | Repel. |
| Keith: | Oh. |
| Teacher: | This means pull together. What does this one mean? |
| Keith: | Unpull. |
| Student: | De-pull. |
| Keith: | Unpull. |
| Teacher: | Unpull. *(Tries not to laugh.)* |
| Student: | Push apart. |
| Teacher: | Push apart. |
| Student: | Pull them apart. |
| Student: | I was going to say that! |
| Student: | With magnets they pull. |
| Teacher: | Push apart. Good. |

Just as with the term *attract,* Mrs. Sinclair confirmed the definition of *repel* linguistically using an intensive relational process in a technical term/everyday term relationship:

| repel | means | push apart |
|---|---|---|
| token | rel:int | value |

This equated the two terms for the students, but whereas *attract* was defined based solely on the students' everyday experience and background knowledge of the concept (e.g., something which a girl does to a boy), Mrs. Sinclair set up the definition of *repel* to be in opposition to that of *attract.* This not only helped the students by giving them a hint about the meaning of a word they might not have heard before, it helped the teacher determine that they understood *pull together* and *push apart* to be opposite concepts.

Unlike the concept of *attract* which was being built up experientially even if not linguistically throughout the twelve stations, the concept of *repel* arose explicitly at only Station Two and Station Eleven. Moreover, at Station Eleven, many of the students were unable to experience the force of repelling because the bar magnets were weak. Instead of feeling the force of repulsion at this station, therefore, the students felt almost no pushing apart, and the teacher was forced to explain what was supposed to happen:

Teacher: But you can't really tell because there's nothing... they're not doing anything are they? Normally they would push apart from each other. Those are not a good... good magnets.

The "nothing" that the students felt at this station was labeled "pushing apart" or "repelling" by the teacher, reinforcing the idea that *pushing apart* or *repelling* was the opposite of *pulling together* or *attracting*, despite the lack of experiential or visual support. By doing this, the teacher was also implicitly reinforcing the idea that one process could be considered the negative of the other:

Teacher: If they don't pull together then we're going to call them pushing apart. Okay?

and later,

Teacher: So south poles together what happens?
Cathy: Mm nothing.
Teacher: Nothing. Nothing... They do nothing or they push apart. I'll take either one of those. Usually in regular magnets they do push apart but in these magnets they don't. So they do nothing.

Although no cause and effect can be established, it is interesting that the lack of repulsion force in this experiment parallels the use of the negative "doesn't stick" in the students later explanations. Certainly these weak magnets were not attracting when identical poles were placed together, but neither were they repelling. They simply were "not sticking," so in fact the students' observations about the rule based on their experiences were accurate. Moreover, even though the students were unable to experience the concept of repelling, this station was the only one in which the technical term *repel* appeared in written text, both in the instructions and in the students' magnet booklets.

At Station Two, however, the two ring magnets presented an excellent example of magnets repelling as one appeared to float over the other. The experiment offered an opportunity to apply the rule of magnetism introduced at Station Eleven, but not all students were able to explore the connection because they had not experienced the force of repulsion at that station, either because they had not yet reached their turn to do that experiment or because of the weakness of the magnets at that station. For most students, therefore, Station Two was an introduction to the concept from an experiential perspective, yet the label for this concept did not appear in the magnet booklets or in the written instructions. It was left up to the teacher to connect the label with the experience here, a feat which the researcher attempted to do with the students who had completed the Station Eleven experiment by having them reason why the top magnet appeared to float:

| | |
|---|---|
| Researcher: | Look what happens in station eleven? |
| Cathy: | It won't stick. |
| Researcher: | And when you put two south poles together? |
| Cathy: | They won't stick. |
| Researcher: | They repel. That's right. And if you've got two north poles together? |
| Cathy: | They repel. |
| Sam: | They repel. |
| Researcher: | They repel. And if you've got one north pole and one south pole? |
| Sam: | They stick. |
| Cathy: | They attract. |
| Researcher: | They attract. That's right. So what do you think is happening here? |
| Cathy: | They're the same side of magnets? |
| Sam: | They repel. |
| Researcher: | They're repelling. So what's— |
| Sam: | Because they're the same type. |

By connecting the two experiments, the students could experience the "pushing apart" talked about at Station Eleven and apply the rule introduced there to what was happening at Station Two. Still, as section 4.3.1 discussed, the students did not become very confident with the use of the term *repel,* and the difficulties associated with constructing the concept as outlined in the current section, as well as the limited use of the term by the teacher and the text, offer a possible explanation for this lack of confidence.

### 4.4.3 Building up an understanding of *north pole* and *south pole*

Out of all the concepts introduced to the students in the magnet unit, the terms *north pole* and *south pole* are probably the most abstract and far removed from the students' everyday experience because there is no useful token/value relation which can be established to offer a translation. When attempting to define these terms for the students on the first day of the unit, Mrs. Sinclair therefore focused on the visible attributes of the magnets, associating the colors with the more abstract, technical terms:

| | |
|---|---|
| Teacher: | North pole... Um... I will just say that the north pole I think is the side which is in gray. |
| Student: | Full of snow. |
| Teacher: | That's all I'm going to say right now. South pole is red. |

Rather than the reversible intensive relational process she used to define *attract* and *repel,* the relation Mrs. Sinclair constructed for the poles was an intensive relational process which was non-reversible:

| | | |
|---|---|---|
| north pole | is | gray |
| carrier | rel:int | attribute |
| south pole | is | red |
| carrier | rel:int | attribute |

Whereas these visible attributes may offer a useful way to help students work between what they see and the technical terms, they are not efficient at defining or translating the terms in ways which may help the students understand the concept. The earlier reversible intensive relational processes allowed the students to shift between their existing understanding of the processes they are experiencing and new labels for these processes. With the non-reversible relation, however, the two sides are not equivalent in the same way. In other words, the students know from their current experience that *north* is *gray* and *south* is *red,* but to learn about magnetism, they must go beyond these experiences to understand that not all magnets are coded this way, yet all have a north and a south pole.

Station Seven, in fact, introduces this idea of possession to the students in the first step of the written instructions:

How can you make a compass by magnetizing a needle?

1. The earth is like a big magnet. It has a north pole and a south pole just like other magnets.
2. Float the cork in the middle of the saucer of water.
3. Magnetize the needle by stroking it 200 times across the magnet. Carefully lay the needle across the cork.
4. Observe what happens. Did the needle turn so it is pointing north and south?
5. Make a diagram of the compass you made.
6. Tap the needle four times on the edge of the table. Put the needle and the cork back in the box.

The text uses a possessive relational process to help the students begin to construct an understanding of polarity and then compares the earth to all magnets:

| | | |
|---|---|---|
| The earth | has | a north pole and a south pole. |
| carrier | rel:poss | attribute |

| | | |
|---|---|---|
| Magnets | have | a north pole and a south pole. |
| carrier | rel:poss | attribute |

The written text therefore does not define polarity for the students in a way which would allow them to translate back and forth between two equal terms, but instead offers them an understanding of the whole–part relationship.

In contrast to the written text at Station Seven, Mrs. Sinclair's definition allows the students to equate *north* with *gray* and *south* with *red* and to translate between the two terms when needed:

| | |
|---|---|
| Brian: | *(Reading.)* Put the south pole north pole... of the two magnets together. Observe what happens. |
| Bob: | The south pole is where? |
| Brian: | The south pole is up here? The south pole is the red. The south pole is down here. |
| Bob: | The south pole. |
| Brian: | Actually... okay the red is south. So we go like this... |

In this excerpt, taken from students working at Station Eleven, Brian has in fact made the relation reversible:

The south pole is the red.
The red is south.

Making it reversible has created a token/value relation, equating both sides of the process just as *attract* was equated with *pull together* (and other processes used by the students to mean *attract)* and *repel* with *push apart.* In fact, the token/value relation seems to be the one most familiar to and productive for the students when they are defining terms, as Table 4.4 showed. The two terms which were being equated in this manner appeared to be (1) equal in the students' minds, (2) consistent with the written explanations on most occasions, and (3) acceptable to the teacher throughout the unit. It is this reversible relation which also appeared to remain in the students' minds after they completed their experiments. In the final question-and-answer period, the attribute of color was typically used instead of the technical terms, *north pole* and *south pole.*

### 4.5 The final question-and-answer period

On the final interactive day of the unit, which was on the third day after the students had finished their last experiment (see Table 4.1), the teacher held a question-and-answer period to find out what they had learned about magnetism. The guiding questions for this were written by the researcher based on the experiments at the stations, and were constructed as well as possible to elicit the two levels of patterning: 1) naming, defining, and classifying, and 2) logical reasoning. The researcher highlighted the questions she most wanted Mrs. Sinclair to ask, but otherwise left the decisions and the flow of the discussion to the teacher.

Mrs. Sinclair asked the students six main questions, but elaborated on those questions as she felt necessary and invited the students to add to their classmates' comments. For the most part, she refrained from making judgments on the correctness of the responses, but instead encouraged the students to express themselves so she could uncover their ideas:

> Teacher: I'm not going to give you any answers. You notice I'm not giving you any answers in this particular thing. I want to find out what your reasoning is and what you think about these things. So that's why I'm asking you.

The basic questions follow. The first question in each number refers to the initial question she asked, and the ones after were questions she used to probe for further information. The label in parentheses refers to the pattern being focused on:

1. What kinds of things do magnets attract? Do they attract all or some metals? (classifying)
2. You can't see magnetism, so how do you know that there is an invisible force? (logical reasoning) What does invisible mean? (defining)
3. What happens when you cut a magnet in half? Why does it still attract? How could this be tested? (logical reasoning)
4. What happens if you put two south poles together? (logical reasoning) What does attract mean? (defining) How can you make two magnets attract? (logical reasoning)
5. What kinds of things does magnetism pass through? (classifying) How do you know it passed through these things? (logical reasoning)
6. How do you make a compass? Why does the needle point north and south? (logical reasoning)

### 4.5.1 Questions which concerned the building of technicality

The students responded to the classification questions easily by offering the names of items which either belonged or didn't belong to the category mentioned. In answering the first question, several students offered examples of items which magnets attract:

> Gary: Metal.
> Celeste: Some money.
> Shelly: The type of metal that um paper clips are made of.
> Brian: Paper clips.

Mandy, however, offered a contrary example of an item which did not fit into the classification, giving a reason for her judgment:

> Mandy: It won't pick up pennies. Because um um on number one there were pennies and um I used a magnet but it wouldn't pick up one penny.

A similar contrary example was given in response to the classification task in question number five. Shelly stated that magnetism can pass through a thin piece of wood, "but if it's a... really heavy piece of wood that's probably like it couldn't." These examples from Mandy and Shelly suggest that the students were constructing at least two taxonomies in response to these classification questions, contrasting what does fit the category with what does not.

The questions which demanded that the students define words appeared to be somewhat more difficult for them. Defining *attract,* a task which had been done on the first day, was not particularly problematic for the two students who offered synonymous terms:

> Gary: Like come attached? *(Later.)* Come together?
> Celeste: They are forced together.

Stanley's response was not an equivalent term but resembled a reasoned explanation of what happens during attraction:

> Stanley: If you have like a little piece of metal and a magnet and you put it there it... like the magnet would attract the piece of metal?

When Mrs. Sinclair asked him if he could say the same thing in another way, he was unable to do so.

The students had more trouble defining *invisible,* a term which had been used at Station Two and Station Eight. When Mrs. Sinclair talked about the "invisible force," she asked what the term meant. In the following definition attempt, Billy tried to address Mrs. Sinclair's question:

> Teacher: What does invisible mean? Billy?
>
> Billy: Kind of... like... like if... you know when the chair shocks you is because like... because like if metal and magnet were touching together like there's this um invisible electricity? [Mm.] That we can't see? [Okay?] And um it's holding... up... kind of like... like the chair was going to shock us when we put it against the metal because it's because we have... um electricity in our hands and when we put it... when we put it to the... metal chair it shocks us.

Billy did not offer clear causal or temporal relations in his explanation. He began with an effort to construct a temporal *when*-clause, but replaced the main clause with the beginning of another *because* relation, yet this is followed by an *if*-clause relation. The only part of his definition which makes a connection between *invisible* and *sight* offered *invisible* as a classifier for the participant *electricity* in a nominal group which is further qualified as something which cannot be seen. The term *invisible* itself is not actually defined by Billy.

Shelly also attempted to define *invisible,* but like Billy, used it as a classifier in a nominal group, reflecting the way Mrs. Sinclair had used it in "invisible force":

> Teacher: Would you like to add to that Shelly?
>
> Shelly: Uh an invisible... thing like it's when... there is something there just that you can't see it because it won't show. [Mm.] Because for some reason it won't show... and you know it's there but it won't show. So that's how you know it would be like.

Shelly's definition came across as being clearer than Billy's until she began repeating herself in her effort to explain why "it" can't be seen.

Despite Shelly's difficulties, she was one of the few students who attempted to use the technical terms which had been introduced, a feat which allowed her conceptual difficulties to be revealed. As a rule, the other students preferred to explain their understanding in the same everyday language which they had brought to the task three weeks earlier rather than use the science words which Mrs. Sinclair had printed on the board and reviewed on Day One. When asked to explain the rule of magnetism, for example, Elly remained dependent on the context:

Elly: The red ones... didn't or the silver... the silver would be right here and the red would be right here. They would attach.

Elly used gestures with exophoric terms denoting location along with the color characteristics of the magnets she had worked with to help her construct the necessary discourse, resulting in a non-academic explanation based on observations. Mandy followed Elly's effort with a more elaborate and complete rule, but she was also anchored in observable participants, everyday processes, and context-dependent locations:

Mandy: It's like well okay you have a red one here and a red one here... if you try and stick them together they won't stick. If you have a gray and another gray they won't stick... but if there's a red and a gray they'll stick.

What is at issue here is not simply the non-use of science words in these explanations, but the lack of conceptual accuracy. Mandy's use of the positive "stick" is by itself debatable as a synonym for *attract* as earlier discussed, but her negative "won't stick" is in no way equivalent to *repel,* yet she is equating the two by her choice of that particular linguistic process in her explanation.

A few turns later, Mrs. Sinclair raised the issue of everyday processes versus scientific processes by asking students what *attract* meant to them when they talked about magnetism. In contrast to the first day, there was no talk of girls and boys in this discussion. Sam responded by attempting to reconstruct the rule of magnetism using scientific terms, but he was unable to complete his explanation:

Sam: Um... when... a south pole and north... a south pole and south pole don't attract? And uh... um... south pole and south pole...

Like Mandy, Sam also chose a negative to replace *repel* when he said "don't attract," resulting in the same conceptual problem as Mandy's discourse suggested. Later, Bob chose "come apart" to contrast with "come together" when constructing his explanation, but aside from his vague participants, his choice still fell short of capturing the concept, primarily because "come apart" lacks the suggestion of causal action that is inherent in *repel:*

Bob: Well um... because if you put like one on one side and one on the other... um I think that... well they they would come together but if you get like both on the same side then they'll come apart.

Interestingly enough, Bob's comment was followed immediately by Shelly saying "It'll repel," but her correct process was never picked up on and addressed; her offering remained the only occurrence of *repel* in this final question and answer period, as revealed in Table 4.11.

**Table 4.11: Processes used to talk about magnetism in the final session**

| Process | Times | Process | Times | Process | Times | Process | Times |
|---|---|---|---|---|---|---|---|
| come attached | 2 | come together | 4 | pass through* | 2 | stay | 1 |
| attract* | 10 | get | 1 | pick up | 10 | stick | 4 |
| be | 2 | go | 1 | pull | 1 | touch* | 1 |
| come | 1 | go through | 1 | pull together* | 2 | turn up | 1 |
| come apart | 1 | hold up | 1 | repel* | 1 | wants to | 2 |

* refers to processes which appeared in the instructional text

Table 4.11 shows that although *attract* was one of the most widely used processes to describe what magnets can do, perhaps because of the discussion of its meaning, there were a total of 20 processes used in this brief period, in which there were 49 utterances containing constructions which involved the magnet as a "doer" of things. *Attract* and *repel* were the targeted science processes in this unit, yet the two together accounted for only 11 of the 49 utterances (22.45%). The process *work,* the most popular choice during the hands-on activities, was not used in this context-reduced session.

### 4.5.2 Questions which elicited logical reasoning

Table 4.12 shows that the use of explicit causal language features was quite high in this question and answer period, reflecting the high number of questions which elicited patterns of logical reasoning. What the table does not show, however, is the difficulty that many of these students had trying to construct their responses. Short answers were typically unproblematic:

Mandy: Um because it's copper?
Shelly: Some type of metals uh keys could be picked up by magnets but not all.
Peter: It still picks up.
Gary: It it's small but still a magnet. It still has the force.

Yet when the students attempted to build longer explanations, they often had difficulty constructing their ideas verbally. To examine this issue more completely, it is useful to look at the temporal and causal relations which were constructed using some of the key conjunctions from Table 4.12.

**Table 4.12: Causal and temporal resources in the question-and-answer session**

| Language Features | no. of times |
|---|---|
| **TIME conjunctions** | |
| and | 7 |
| and then | 3 |
| then | 2 |
| after | 1 |
| still | 5 |
| already | 1 |
| when... then... | 9 |
| **TIME participants** | |
| number four | 1 |
| **PLACE circumstances** | 17 |

| Language Features | no. of times |
|---|---|
| **CAUSE conjunctions** | |
| because | 12+3* |
| so | 3 |
| if... then... | 16 |
| **CAUSE processes** | |
| make (X do Y) | 2 |
| **CAUSE circumstances** | |
| for some reason | 2 |

Items with an * indicate aborted explanations (i.e., unfinished thoughts)

| Language Features | no. of times |
|---|---|
| **MEANS circumstances** | |
| by doing it | 1 |
| by a different position | 1 |
| **PASSIVE VOICE** | 3 |
| **NOMINALIZATIONS** | |
| an invisible thing | 1 |
| invisible electricity | 1 |
| the force | 1 |
| **LEXICAL DENSITY** | 35.3 |

The use of *because* in a causal relation is clearly illustrated in the following two excerpts:

Mandy: I used a magnet but it wouldn't pick up one penny.
Student: It's copper.
Mandy: Um because it's copper.

Teacher: Why does the needle point north and south?
Cathy: Because the needle is a magnet.

The first example forms the causal relation *not X because Y,* where the negative *X* is "it wouldn't pick up" and the positive *Y* is "because it's copper." Similarly, the second excerpt could be considered *(X) because Y,* where the teacher offered the *X* in her question, and the *Y* was Cathy's response. Table 4.13 presents the variety of relations which were present in the students' discourse of the final question and answer period. The parentheses indicate that the teacher has supplied the initial clause(s), as in the latter excerpt above.

As illustrated earlier, Billy's definition lost clarity as he repeated words and embedded one relation in another. Bob, Sam, and Shelly had similar difficulties with aborted and/or embedded relations when they attempted novel explanations of abstract ideas:

Teacher: So how do you know that there is an invisible force? Bob?

Bob: Because um... there even when you can't see it you could somehow you could put it between the magnets and there's a kind of you know if feels kind of real? But another way to prove it is that... you could take another uh thing the magnet will attract to and will be attracted... and then and it would be hard to to like explain... if there wasn't one... like I mean an invisible thing.

Teacher: How do you know that the force passed through that?

Sam: Well there's like... there was this paper clip stuck to a piece of a string and to a piece of wood and you have a magnet bar... because the piece of plastic or whatever it it it um the magnet had enough power to attract to the... paper clip and then it it kind of... they tried to pull together so that makes the plastic stay between the paper clip and the magnet.

The difficulties the students had articulating their ideas made their efforts sound as though they were thinking out loud, as if these were their first attempts at explaining these ideas—which, based on the discourse examination of the experiments, they were.

**Table 4.13: Causal and temporal relations in the question-and-answer session**

| | | | |
|---|---|---|---|
| X because Y | 4 | when X, then Y | 5 |
| (X)* because Y | 4 | (when X), then Y | 1 |
| X because not Y | 1 | X when Y | 1 |
| not X because Y | 2 | when X... | 3 |
| not X because not Y | 1 | if X, then Y | 11 |
| X because X | 3 | (if X), then not Y | 2 |
| X, so Y | 3 | if X, then not Y | 3 |
| do X and Y happens | 1 | X if Y | 1 |

**Less congruent forms**

| | |
|---|---|
| X makes Y do something | 2 |
| do X to do Y | 3 |
| (X) by doing Y | 1 |

*Items in parentheses indicate another speaker.

It was not just the articulation of novel, abstract concepts that presented problems for the students. Mrs. Sinclair asked them how to make a compass, a task which they had all done at Station Seven. Elly, who attempted the instructions first, missed key information about cause and effect. Eddy recalled the goal of the experiment and his language reflected the causal nature, but he also missed a step. Stanley finally filled in the missing piece:

| | |
|---|---|
| Elly: | Um you get a dish a wah... you get a dish of water? |
| Teacher: | Yes? |
| Elly: | And you take a cork and needle... then you put the cork in the water and the needle on top of the cork. |
| Teacher: | Good. Is there anything you want to add to that? |
| Elly: | Oh no. |
| Teacher: | Okay. Does anybody else have anything to add to that? Eddy? |
| Eddy: | Well... then what you would do is... I know there's a part and it... where you would try and make it point to... the south and north. |
| Teacher: | Yes?... Good?... Was there anything else? One step that we're perhaps missing or do you know of any other step that we could perhaps put in there that we haven't talked about there? Stanley? |
| Stanley: | Like you have to pick... take the needle and stroke it on a magnet to get the magnetic force inside your needle. |

Whereas Elly's information may have resulted in something that resembled a compass, it was missing the element that would cause the needle and cork to become one. Eddy picked up on the lack of causality and supplied help by offering "you would try and make it point." Stanley then filled in the missing piece by offering the instruction that would allow the compass builder to "make it point." He explained that you had to "get the magnetic force inside your needle" and gave his audience information about how to do this.

Although the language of these instructions is not lacking clarity as the earlier examples of explanations of abstract concepts were, it is nonetheless interesting to note that it took three students to reconstruct the directions. It was even more interesting to notice that Shelly had created her own causal connections about the rubbing of the needle:

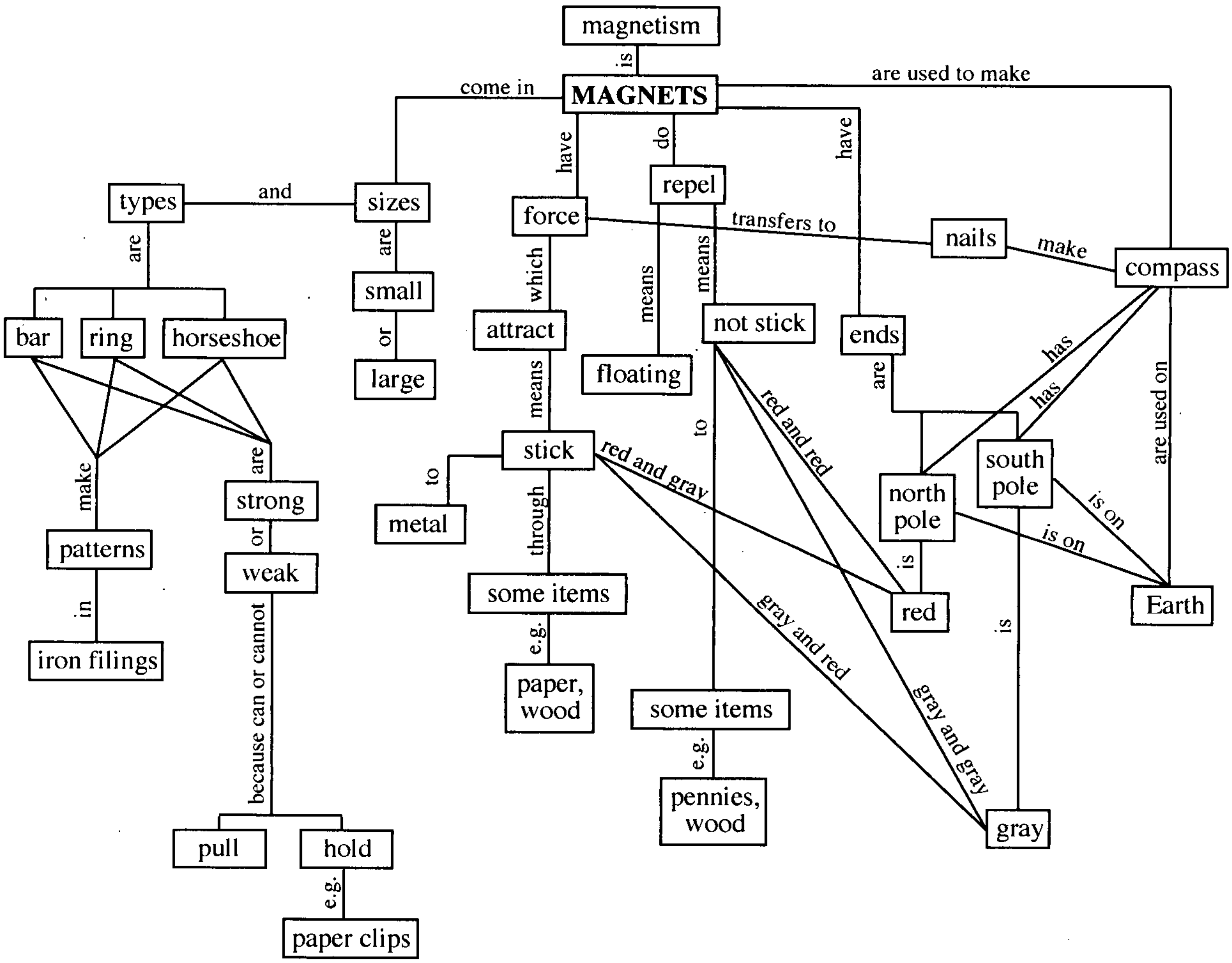
| | |
|---|---|
| Shelly: | Um after you stroke it two two hundred times on it? Well there's a magnet and the magnet has two parts a south pole and a north pole. And which side you were... um scratching on was south or north and they will be going south and north. |

Not only is Shelly illustrating problems of clarity—this time through a combination of temporal and classification language features—it appears as though she believed that the pole she was stroking the needle on determined which way the needle would face once it was on the cork in the water. This suggests that Shelly was continuing to struggle with the abstract ideas of magnetism and was trying to make connections between these new concepts (the magnet's north and south) and her everyday concepts (the directions of north and south).

### 4.6 Summary

This chapter has described in detail how Mrs. Sinclair's class learned about magnetism, focusing on how the field was constructed through renaming, redefining, and reclassifying everyday things to create technical taxonomies, and how these technical terms were—or perhaps were not—used by the students to sequence and explain events through logical reasoning. The concept map which was created by the discourse, drawn following Novak (1998) based on the classroom discourse, is shown in Figure 4.1.

**Figure 4.1: Mrs. Sinclair's unit as a concept map**




Mrs. Sinclair introduced the key terms through spoken language at the beginning of the unit and hoped that the students would connect the language with the experiences they had at the twelve stations. The students moved through these stations at different times, reading the written instructions and talking at times with their classmates and at times with the teacher or researcher. On the last day of the unit, the students were questioned about their experiences, but it was found that the language they used continued to be the same everyday language that they had initially brought to the task, terms such as *stick, doesn't stick, red,* and *gray,* rather than the field-specific lexis which is required to construct an understanding of magnetism. Whereas it is impossible through an examination of the data to establish any cause-and-effect relationship to respond to why their language remained the same, Section 4.4 described what appeared to be a tendency by the students to construct reversible intensive relations (e.g., token/value relations) when defining the key terms, relations which equate *X* and *Y*:

| | | |
|---|---|---|
| X | is | Y |
| attract | is | pull together (stick, work, etc.) |
| repel | is | push apart (not stick, unpull, etc.) |
| north pole | is | gray |
| south pole | is | red |

Table 4.4 showed that the students' preferred definition format was that of the token/value (i.e., reversible) relation, and their discourse throughout the unit suggested that they used the Xs and the Ys interchangeably. For the most part, neither the written text nor the teacher consistently used the experiential aspects of the experiments to redefine and rename the everyday "values" to construct the new technical "tokens."

Regarding the reasoning and explaining level of patterning, congruent conjunctions were much more common in the students' speech than non-congruent forms and there was minimal use of grammatical metaphor aside from the passive of *attract.* The process *make* was the most common causal process used. What was also striking was the high number of causal conjunctions over temporal ones, reflecting both the students' understanding of the causal nature of magnetism and their attempts to explain what they were experiencing as they worked through the experiments. Out of these causal conjunctions, *because* was the most frequently used in the discourse of the experiments, followed by *so* and the conditional *if*-clause. In the final question-and-answer period, however, the *if*-clause was slightly more common than *because,* likely reflecting the teacher's focus on explaining the rule of magnetism.

# CHAPTER 5: MRS. MONTGOMERY'S PRIMARY SCIENCE CLASS

## 5.0 An overview of the chapter

Whereas Chapter 4 examined the construction of knowledge in Mrs. Sinclair's class, Chapter 5 offers a detailed look at how Mrs. Montgomery helped her students learn about magnetism. As with Chapter 4, the emphasis in this chapter is on how the teacher approached the two types of patterning which Halliday argues are involved in constructing science knowledge: the renaming, redefining, and reclassifying of common-sense things into technical taxonomies, and the reasoned sequencing which draws on these technical entities. Chapter five addresses the following research questions:

1. How do Mrs. Montgomery and her students develop causal explanations and their relevant taxonomies through the classroom interactions?
2. What are the causal discourse features being used by Mrs. Montgomery's students to construct oral causal explanations?

This chapter follows a structure similar to the previous one, beginning with a general description of Mrs. Montgomery's magnet unit. This is followed in Section 5.2 by a discussion of how the teacher created technicality and promoted reasoning during the classroom interactions which were held before, after, and while the students carried out their experiments. Section 5.3 tracks the construction of the four key concepts which were tracked in chapter four—*attract, repel, north pole,* and *south pole*—describing how an understanding of these terms was built up throughout the unit. Section 5.4 details the language of the interviews which six students participated in, illustrating the same two levels of patterning which they used to construct knowledge about magnets: technicality and logical reasoning. The chapter concludes with a summary of the key points.

## 5.1 Mrs. Montgomery's magnet unit

The magnet unit's original format (as it was used for Mrs. Sinclair's class the previous year) was modified by the researcher based on recommendations made by Mrs. Montgomery because of the demographics of the students. Table 5.1 shows the format of the unit for these classes. Because of the high number of ESL students at Merrydale School, the teacher needed a format through which she could teach all the students the same information at the same time, so that they would be equipped with the language and concepts they needed for the task and a clear understanding of the task itself. For this reason, on each day all stations had the same equipment set up so that the students could do the same experiment, and Mrs. Montgomery spent time talking with the class before and after each experiment. A full description of these experiments appears in Appendix 3.

**Table 5.1: Mrs. Montgomery's magnet unit**

| Date | Classes | Experiment or task |
|---|---|---|
| Wednesday, November 7, 2001 | A, B, C | What does a magnet attract? |
| Wednesday, November 14, 2001 | A, B, C | The strongest parts |
| Wednesday, November 21, 2001 | A, B, C | The strongest magnet |
| Friday, November 23, 2001 | A, B, C | The power of magnetism |
| Monday, November 26, 2001 | A, B, C | Magnetism in a chain |
| Wednesday, November 28, 2001 | A, B, C | Making a magnet |
| Friday, November 30, 2001 | A, B | Making a compass |
| Monday, December 3, 2001 | A, B, C | Showing the force |
| Wednesday, December 5, 2001 | A, B, C | Attracting and repelling |
| Friday, December 7, 2001 | A, B, C | An invisible force |
| December 10 to January 31 | A, B, C | Writing activities |
| February 22, 2002 | Six Children | One-on-one interviews |

On the first day of the unit, Mrs. Montgomery told the students that they were going to learn about magnets and do several experiments. She told them about the audio recorders and cautioned them not to put the magnets near them. She introduced the researcher briefly and then began outlining the day's lesson. At the beginning of each subsequent class, Mrs. Montgomery spent time getting the students to recount the previous day's experiment and asking them questions about what happened and why. She made no negative judgments about the explanations beyond insisting on the use of "science words," and she praised the students if there was evidence of critical thinking and logical connections to other experiments they had done.

After reviewing the previous experiment, Mrs. Montgomery introduced the current day's work, going through the needed key terms and showing the students the materials they would be working with. She elicited the students' labels for these items and printed the correct terms on chart paper attached to the wall at the front of the whole-group area, along with a hand-drawn representation of the item which she did while the students watched. She then both told and showed the students what they would be doing in their experiments, but withheld the findings or results from her demonstration. She then asked the students for their predictions about what might happen, and after eliciting some ideas, distributed the magnet booklets and asked the students to write their predictions in their booklets.

Once Mrs. Montgomery had finished outlining the day's task and the students had made their predictions in their booklets, they spent ten to fifteen minutes doing hands-on work with the three adults (Mrs. Montgomery, the regular classroom teacher, and the researcher) asking them questions about what they were doing. (During experiment seven, they spent over twenty minutes making their compasses.) At the end of this time, Mrs. Montgomery called the students to attention, asked them to put the equipment back in the plastic containers, and directed them to return to the "meeting spot." Once the students were seated back at the whole-class area of the room, Mrs. Montgomery asked them what they had done at their stations and what they had discovered. She went over the conclusion in the magnet booklet and made sure that all students had formulated a reasonable response, which she often printed on the chart paper once the students had supplied the information. This review session typically lasted between five and ten minutes.

After the students had finished the ten experiments, Mrs. Montgomery visited their regular classrooms and once again reviewed the experiments in preparation for the writing activities. Using key visuals based on the magnet experiments (see Appendix 4), the students wrote classification texts (types of magnets, types of objects attracted to magnets, types of objects magnetism passes through), cause-and-effect texts (the rule of magnetism), and sequencing texts (making a compass). Not all students wrote all texts, although all wrote some; participation in the writing tasks was at the discretion of the regular classroom teachers, and some had decided to move on from magnets.

On February 22, 2002, the researcher met with and interviewed six students, recommended by Mrs. Montgomery for their lack of shyness in speaking, about their understanding of magnetism. This was not part of Mrs. Montgomery's overall teaching plan for the unit, but she set up the interviews and welcomed the feedback so that she could improve the unit for the next time she taught it.

### 5.2 Constructing knowledge in Mrs. Montgomery's class

Mrs. Montgomery's intention for this unit was to have the students learn about magnets and be able to use specific vocabulary—what she referred to as science words—to talk about what they had learned. She insisted that if teachers do not teach the language that goes with the science content, they are "not doing the children any justice or the preparation" that goes into the science lesson. Although she focused on what she felt was the students' vocabulary learning, her goal was to have the words become "part of their language" so that they could explain their understanding clearly:

> The language is vocabulary but it's more than that. Language is... getting an understanding of the vocabulary. A deep down understanding. So a comprehension. Language to me is being able to use... words... in such a way that it shows that they understand the whole concept. That's the language. (Interview with teacher)

Mrs. Montgomery's focus on language reflected the two levels of patterning which Halliday argued are involved in constructing science knowledge. How she did this will be discussed in the next two sections.

#### 5.2.1 Building technicality: Renaming, redefining, and reclassifying

Mrs. Montgomery's attitude towards the use of science language surfaced frequently as she and the other teachers, as well as the participating researcher, prompted students to use the correct terminology:

> You don't want to be using that word. (on hearing "sticks" in Experiment One)
> Tell me in science language though. (Experiment Three)

Stick? (Experiment Four)
Maybe that wand is—what's that word rather than stick? (Experiment Five)
What's that word? (Experiment Six)
What's that word I'm looking for? (Experiments Seven and Eight)
Can you give me some science words? (Experiment Nine)
What's the word we've been practicing? (Experiment Nine)
Glue sticks. That's not scientific though. What's the word? (Experiment Ten)

This prompting combined with modeling appeared to influence the students early on and they began to pay attention to their language. Examples of self-correcting and correcting each other surfaced early and consistently in various ways:

Student self-correcting (Experiment One):
Researcher: Now what's happening to the quarter?
Student 1: It sticks.
Student 2: It sticks. Attracts.

Student correcting another student (Experiment Four):
Student 3: Look! That sticks!
Student 4: No! Not sticks.
Student 3: Attracts.

Student self-correcting by asking for help (Experiment Nine):
Student 5: It sticked. No. What's the word for that?
Student 6: Attract.

Mrs. Montgomery's insistence on the correct science words for the processes was accompanied by *attract* and *repel* being among the students' most popularly used processes for talking about what magnets do, as Table 5.2 shows. In fact, out of 584 occasions in which the students talked about what was happening with the magnets, *attract* was uttered 178 times (30.48%), more than twice as frequently as the next most popular, *stick* (86; 14.73%). The word *work* appeared only 83 times (14.21%). *Repel,* a concept which was introduced during Experiment Nine, was used 72 times (12.33%) by the students in the two experiments which required the use of the term.

Although *attract* was uttered frequently throughout the experiments, it was not always used correctly, just as in Mrs. Sinclair's class. In Experiments Five, Nine, and Ten, where magnets were attracted to each other, the students did not have noticeable problems. Nor did they have trouble when it was obvious that it was the magnet or magnetized item which was doing the attracting, as in Experiments Six and Seven. Yet when the students were

## Table 5.2: The students' processes of attraction

| | Stations | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total (/584) |
| attach | 1 | 1 | 2 | | | | | | | | 4 |
| attract | 33 | 12 | 3 | 9 | 10 | 9 | 6 | 5 | 52 | 39 | 178 |
| be | | | 3 | | | | | | | | 3 |
| bounce | | | | | | | | | | 1 | 1 |
| come | 2 | | | | | | | | | | 2 |
| come off | | | 1 | | | | | | | | 1 |
| come together | | | | | | | | | | 1 | 1 |
| dance | | 2 | | 2 | | | | | | | 4 |
| do | 5 | 2 | 1 | 3 | 1 | 1 | | | | | 13 |
| drop | | | | | | 1 | | | | | 1 |
| explode | | 2 | | | | | | | | | 2 |
| fall | | | | | 1 | | | | | | 1 |
| float | | | | | | | | | | 3 | 3 |
| fly | 2 | | | 1 | | | | | 9 | | 12 |
| get | | 6 | 1 | | | | | | | | 7 |
| go | 4 | 3 | 1 | | 2 | | 2 | | 2 | | 14 |
| go through | | | | 4 | | | | | | | 4 |
| hang | | 1 | | | | | | | | | 1 |
| hang down | | 1 | | | | | | | | | 1 |
| hang on | | | | | | | | 1 | | | 1 |
| hate each other | | | | | | | | | 1 | | 1 |
| have | | | 1 | | 1 | | | | | | 2 |
| hold | 2 | 1 | 2 | 2 | | | | | | | 7 |
| hold up | | | | | | | | | | 2 | 2 |
| jump up | | | | | | | | | | 1 | 1 |
| let go | | | | | | | | | 1 | | 1 |
| lift | | | 1 | | | | | | | | 1 |
| like | | | | | | | 1 | | | 1 | 1 |
| like each other | | | | | | | | | 1 | | 1 |
| look | | | | | | | 1 | | | | 1 |
| make | 2 | | | | | | | | | | 2 |
| make (causative) | | | | | 1 | | | | | | 1 |
| move | | | | | | | 6 | | | | 6 |
| move around | | | | | | | | | 1 | | 1 |
| move away | | | | | | | | | 1 | | 1 |
| pick up | | 1 | 2 | | | | | | | | 3 |
| point | | | | | | | 11 | 1 | | | 12 |
| pull | 2 | | | | | | | | 1 | | 3 |
| push | | | | | | | | | 4 | | 4 |
| put together | | | | | | | | | 1 | | 1 |
| repel | | | | | | | | | 42 | 30 | 72 |
| snap | 1 | | | | | | | | | | 1 |
| spin | 1 | | | | | | 1 | 1 | 1 | | 4 |
| stand up | | | | | | 1 | | 1 | | | 2 |
| stay | | | | | 1 | | 1 | | | | 2 |
| stick | 33 | 6 | 1 | 6 | 2 | 6 | 3 | 4 | 15 | 10 | 86 |
| take | 1 | | | | | | | | | | 1 |
| take out | | | | | | | | | 2 | | 2 |
| touch | | | 1 | | | | | | | | 1 |
| turn | | | | | | | 10 | 1 | | | 11 |
| turn around | | | | | | | 1 | | | | 1 |
| turn away | | | | | | | | | 1 | | 1 |
| turn down | | | | | | | 1 | | | | 1 |
| unattract | | 1 | | | | | | | | | 1 |
| want | | | | | | | | | | 1 | 1 |
| want to... | | | | | 5 | | | | 1 | | 6 |
| work | 24 | 7 | 2 | 20 | 3 | 12 | 6 | 1 | 3 | 5 | 83 |
| *zact | | | | | | | | | 1 | | 1 |

*refers to invented word

**Table 5.3: The students' use of *attract* in Experiment One**

| Form of *attract* | Example sentence | No. of times (/33) |
|---|---|---|
| passive, no agent | This **is attracted.** | 7 |
| passive, human subject | I **am attracted to** the magnet. | 3 |
| active, magnet as agent | It **attracted** metal. | 4 |
| *active, item as agent | The nail **attracted.** | 15 |
| *active, human subject | I **attracted** the nail. | 1 |
| *active with *to* | Oh it doesn't **attract to** that. | 1 |
| as heading | Not **attracted.** | 2 |

Items marked with an * indicate incorrect construction.

testing various items or testing the power of magnetism through various items, they were inconsistent regarding which participant was doing the attracting. Experiment One most clearly illustrated this problem, although the discourse reveals examples throughout several of the experiments, as it did in Mrs. Sinclair's class. In Experiment One, as Table 5.3 illustrates, out of thirty-three examples of *attract* in the students' oral text, there were two references to the heading *not attracted* in their magnet booklets. There were seven occasions where the students used the agentless passive. There were three examples where the student became a subject in the passive construction. The other examples used the active voice, and out of these, there were only four instances in which the magnet was clearly the "doer" of the attracting. In one example, the student was the "doer," using the circumstance of means "with these two," yet the "two" that the student referred to were not magnets, but two of the items being tested:

Student: I want to see something. Look. Look at that. Guess what I did. See? I did it with these two. I attracted the nail. Look at that.

There was also one example where an item *attracted to* the magnet, but in the majority of examples, the item being tested was the item given the ability to attract.

As the discussion in section 4.3.1 of Mrs. Sinclair's class suggested, there is evidence that the students were simply equating *attract* to *stick* without understanding the role which the actor plays in the construction. The evidence is further revealed in this class by the students' self-corrections, which replaced the everyday with the technical, as shown earlier, and in Mrs. Montgomery's prompting for the correct word.

Although infrequent, there were constructions which implied that there was a human participant as the subject when in fact the subject was a magnet. For example, in Experiment Five, the teacher asked a student why putting the eighth magnetic marble on the chain consistently resulted in a broken chain. The student answered, "Because it's scared." When asked in Experiment Nine why the two poles were repelling, Isaac responded with a process typically associated with human qualities: "Because they want to repel." When the teacher asked another student nearby the same question, the response was simply that "they hate each other." In the same experiment, three students were manipulating the two bar magnets and commented:

Walter: Oh look. They're repelling.
Student 1: Try to push them tight.
Student 2: No. They don't like each other. They repel.

This last example suggested that the poles repel because they don't like each other, reflecting observations which Shelly consistently made in Mrs. Sinclair's class.

During the experiments, many of the participants in the processes being described were exophoric, just as they were in Mrs. Sinclair's class. The students frequently referred to items as *this, it,* or *those,* and to places as *here* or *there*. Yet during the whole-class discussions in which the teacher asked the students to say what they had done, the language became more endophoric to compensate for the reduction of context. Although the students usually referred to the objects by name during these discussions, at times Mrs. Montgomery had to request clarification:

Clarifying the participant (Experiment Seven):
Teacher: How did you know that you had made a magnet?
Student: Because um you try if it sticks.
Teacher: You try if it sticks.
Student: It attracts.
Teacher: You try if what sticks?
Student: The nail and the pin?

Clarifying the process (Experiment Eight):
Teacher: What happened to the needle and the cork?
Student: I saw it move.
Teacher: You saw it move. Did it jump up and down?
Student: No!

Teacher: What did it do?
Student: It turned around.
Teacher: It turned around.
Student: To north.

Specifying scientific participants (Experiment Nine):
Student: We got the um
Teacher: We got the what? What is it?
Student: The black thingy?
Teacher: The black thingy? What's the black thingy?
Student: The black?
Teacher: Come. Come and show me. Like this? Who remembers what this is called?

In the last example, the teacher had the student physically identify the iron filings and then asked the students to try to remember what they were called. The term had been introduced in the previous lesson, and this "naming game" encouraged everyone to think about what they had done. Once the correct label was supplied, Mrs. Montgomery had the students describe what the iron filings looked like and explain what had happened when they were held near a magnet, which was the experiment the students had done in the last lesson.

It is this effort to describe and explain orally which appeared to be the goal of Mrs. Montgomery's science lessons. She was not particularly concerned about the students' writing and spelling, and often told the students that spelling did not matter in their magnet booklets. In the first experiment, she offered them the choice of printing the names of the items or drawing pictures of them. But she did not sever the connection between the oral and the written text entirely. She printed key words on chart paper so that they would be available for the students to copy. Moreover, when introducing the terms *north pole* and *south pole,* she brought attention to the initial sounds of *north* and *south* and asked what these letters were before pointing out that the *N* and the *S* were imprinted on all but the ring magnets. Regarding the magnet booklets, though, she insisted that *N* or *S* were adequate, and that the students did not need to write the full words if they chose not to. Many of the students called the poles *N* and *S* when they spoke during the experiments, although most used the full words during the context-reduced discussions.

Mrs. Montgomery focused on the meanings and grammar relevant to science rather than general grammatical errors, as the following two examples show:

| | |
|---|---|
| Victor: | They aren't stick. They aren't stick. |
| Teacher: | Why? |
| Victor: | Maybe this made of something with metal? Maybe this made with something else. |
| Student: | They're danger. |
| Teacher: | They're not dangerous.... You just have to be careful when you touch them. |

On one occasion in the discourse data (Experiment Five), the teacher focused briefly on a grammar point which was relevant to the science meaning she was constructing. She had anticipated hearing the word *force,* which she had previously introduced and visually associated with strength and strong muscles:

| | |
|---|---|
| Teacher: | What science word did we use? The? |
| Student: | Strong. |
| Teacher: | Strong? How? Like is it the strong of magnetism? |
| Student: | Strength. |

The teacher accepted this answer, then made the connection between the word *strength* and the experiment which the students had done to find out which was the *strongest* magnet. She then asked about the previous experiment, where the magnetism went through the glass to attract the safety pin. Reminding the students of this particular experiment prompted one to recall the term *force,* and the discussion continued. This emphasis on finding the correct part of speech was not a grammar correction as such (language as rule), but instead it was used as a probe for the students to recall what they had been doing in other experiments so that they would be better able to describe and explain their current findings (language as resource).

The students in Mrs. Montgomery's class often described what they saw in terms of the relational process *looks like.* Mrs. Montgomery used this process in questions to get the students thinking about the names of the magnets and to make sure they knew what to draw in their magnet booklets ("Show me what it looks like"). The horseshoe magnet, for example, was initially called a U magnet because of its shape until the teacher labeled it a horseshoe magnet and explained what a horseshoe was. The ring magnet was called an O magnet until the teacher put it on her finger and the students called out "ring." One student commented that the ring magnet "looks like a hat," and another declared that it "looks like a cookie." When the pins were attracted to the poles of the magnets in Experiment Two, some students declared that the result looked like a swing or a necklace. In Experiment Eight, the patterns that the iron filings created when put near the magnets looked like a flower, a man, a monster, a ghost, or a boat, according to the students. These types of constructions, combined with sentences using processes such as *stick* or *dance,* made the discourse at times seem quite unscientific, yet using these processes and participants usually enabled the students to describe what they had seen and done, and with the prompting and probing of the teacher at the beginning and end of each session, the more appropriate processes and participants became part of the students' explanations.

By the end of the ten experiments, Mrs. Montgomery was satisfied that the students' language and knowledge concerning magnetism had developed and that they were aware of the appropriateness of their word choice for science. She was pleased to see them self-correcting and correcting others in the class. She followed the experiments with writing activities, and from listening and reading the texts that the students constructed, she felt that they were confident using the language they had learned:

> Teacher: They could use it... during their experiments... They could use it in their writing. When we were talking in the classroom... They could tell me all of the different kinds of magnets. We practiced them. It was just part of their language. Eventually it just became part of their language. (Interview with teacher)

This had been Mrs. Montgomery's goal, and by the last few experiments, it appeared that the students' ability to talk about magnets had indeed developed.

### 5.2.2 The magnet experiments and logical reasoning

Mrs. Montgomery's focus on sequencing and reasoning was made evident by the number of questions she posed which asked *why* or *what is happening*. Table 5.4 shows the frequency of these questions. Moreover, the table shows that there was an effort during each lesson to make connections to other experiments. These connections, according to Mrs. Montgomery, were an important part of her teaching strategy, as they allowed her to "layer" the information and build language skills and concepts by frequently reviewing the content:

> Layering is such a key thing to do... because they [the students] need to be able to make that smooth connection from one day to the next... and know that just because they used a bar magnet one day it doesn't go away and it never comes back again. (Interview with teacher)

Reflecting her own preference for questions and connections, Mrs. Montgomery praised students for remembering information from previous experiments and for asking questions.

**Table 5.4: The frequency of Mrs. Montgomery's questions and connections**

| | **Experiment numbers** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **Total** |
| teachers/researcher asking *why* | 33 | 17 | 5 | 1 | 19 | 4 | 11 | 18 | 3 | 17 | 128 |
| teachers/researcher asking *what happens* | 5 | 7 | 0 | 4 | 7 | 4 | 11 | 14 | 33 | 40 | 125 |
| teachers/researcher making connections to other experiments | 0 | 2 | 2 | 4 | 7 | 5 | 6 | 6 | 3 | 8 | 43 |

With so many questions prompting recounts and explanations, one would expect that there would be a high frequency of lexicogrammatical features characteristic of causal explanations. Table 5.5 shows the number of causal language features which surfaced in the students' discourse across the ten experiments. The causal conjunction *because* was by far the students' most popular resource for explaining their understanding (76; 38.5%), and the majority of these responses (66 out of 76; 83.54%) were answers to the teacher's *why*-questions:

| | |
|---|---|
| Teacher: | Why do you think it's attracted to the magnet? |
| Student: | Because it's both metal. They're both metal. |

There were also three examples of a circumstance of cause, *because of,* in the students' discourse, although one of these examples was missing the *of* and was therefore grammatically incomplete. The conjunction *so* was used very infrequently (9; 4.57%).

**Table 5.5: The students' use of causal language features in the ten experiments**

| | Experiment numbers | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Language Features** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **Total** |
| **TIME conjunctions** | | | | | | | | | | | |
| and then | | 1 | 1 | | 2 | 1 | | 3 | 1 | 2 | 11 |
| then | | 1 | | | 1 | | | 4 | | | 6 |
| now | | | | | | 1 | | | | 1 | 2 |
| still | | | | | | 1 | | | | | 1 |
| until | | | | | | | 1 | | | | 1 |
| once | | | | | | | | | 1 | | 1 |
| after | | | | | | | | | 1 | | 1 |
| when... then... | | | | 1 | 1 | 1 | 6 | 3 | 18 | 8 | 38 |
| **TIME participants** | | | | | | | | | | | |
| the first one | | | 1 | | | | | | | | 1 |
| last time | | | | | | | | | | 1 | 1 |
| **TIME circumstances** | | | | | | | | | | | |
| at the same time | | | | | | | | | | | 1 |
| **PLACE circumstances** | 11 | 29 | 4 | 6 | 2 | 1 | 8 | 8 | 1 | 5 | 75 |
| **CAUSE conjunctions** | | | | | | | | | | | |
| because | 11 | 13 | 6 | 2 | 6 | 4 | 10 | 7 | 2 | 15 | 76 |
| so | 4 | 2 | | | | | 2 | 1 | | | 9 |
| if... then... | 4 | 2 | 1 | 2 | 3 | 1 | 5 | 2 | 4 | 27 | 51 |
| **CAUSE processes** | | | | | | | | | | | |
| make (X) | | 1 | | | | 1 | | 2 | | 1 | 5 |
| make (X do Y) | 1 | | | | 1 | | | 1 | 2 | 1 | 6 |
| **CAUSE circumstances** | | | | | | | | | | | |
| because of | | | | | 2+1# | | | | | | 2+1# |
| **MEANS circumstances** | | | | | | | | | | | |
| with these two | 1 | | | | | | | | | | 1 |

The "of" was left out of the example with the #.

The dependent clause of cause, the conditional *if*-clause, was the second most popular feature in the students' discourse (51; 25.89%), although 28 examples of this (54.9%) were set up by the teachers or researcher who framed their questions to elicit a short response.

Teacher: What would happen if I put this end with this end?
Student: It attracts.

The *when*-clauses (38; 19.29%) were similarly co-constructed, with the teachers or researcher helping to set up these temporal relations 28 out of the 38 occasions (73.68%):

| | |
|---|---|
| Teacher: | Right. And when we have two souths coming together they are going to? |
| Student: | Um repel. |

The teacher's questions were not always answered using explicit causal language features. Sometimes this was because the teacher supplied the causal lexis and the student needed only to complete the missing information:

| | |
|---|---|
| Teacher: | What did you find out in the end? The sometimes magnet is strongest because... something. |
| Student: | It lifted more of... the paper clips. |

But at other times, there seemed to be no specific reason for the students choosing not to use *because* in their attempts. There were in fact 21 occasions in this class where the teacher's questions were answered without explicit causal discourse, as in the following example:

| | |
|---|---|
| Teacher: | Why doesn't the key... what do you think Jenny? |
| Janie: | It doesn't. The key's small. |
| Teacher: | It's because it's too small? Why do you think Annie? Why do you think it doesn't... Why do you think it isn't attracted? |
| Abby: | Mm... it doesn't attract. I don't know. Maybe it's not metal? |

In many other examples, however, the students' response began with *because*.

As the previous discussion suggests, the teacher played a key role in the students' explanations. Without the probes, there was usually little effort made by the students to do anything more than offer general observations or exhibit controlling discourse over whose turn it was or what to do next, as the following excerpt from Experiment Ten shows:

| | |
|---|---|
| Student 1: | You go like this. |
| Student 2: | How do you know? |
| Student 1: | You go like this. Take that out. |
| Student 2: | Oh yes. |
| Student 3: | This is cool! |
| Student 1: | I'm going to test this. Watch this. |
| Student 2: | It jumps up. |
| Student 3: | It's floating. It's floating. It's so funny. |

Yet when one of the teachers or the researcher approached and began asking questions, the students offered their explanations and descriptions as requested. In this experiment, for example, students at their stations were directed to consider the rule of magnetism, or what they learned in the previous class, to predict which side of the ring magnet was south and which was north. Then during the whole-class discussions which began and ended each session, they were again asked to explain and predict, prompted by the teacher's questions, as the following lengthy dialogue shows:

| | |
|---|---|
| Teacher | Boys and girls look carefully at the diagram. What does our first diagram look like? Or what does one diagram look like? Do they both look like this? |
| Students | No. |
| Teacher | No. What do they look like Walter? |
| Walter | North and south. |
| Teacher | That's right. So... what happened here? |
| Students | It repelled. |
| Teacher | They're repelling. Right. They were repelling and I'm going to turn this one over. What do we call this? North or south? |
| Students | North. |
| Teacher | North. It doesn't matter. I'm turning it over. What... |
| Student | Attract. |
| Teacher | So if it's attracting what is underneath here? North or south? |
| Students | South. |
| Teacher | South. Right. The bottom is probably north and this part is south. Does it matter? No it doesn't. This could be north. This could be south. This could be north or this could be south. Why? Because? |
| Student | Because north and south. |
| Teacher | Because north and south and what do north and south always do? What is the rule? |
| Students | Attracts. |
| Teacher | That's right. North and south always attract. What repels? |
| Student | North and north or south and south. |
| Teacher | Yup. North north. That's repel. |
| Student | South and south repel? |
| Teacher | North and north repel. So north and north repel and south and south repel. So these two could be either what? |
| Student | North and north. |
| Teacher | North and north or south and south. You're right. What do we know for sure that one is going to be? |
| Student | North. |
| Teacher | And one is going to be? |
| Student | South. |
| Teacher | South. Right. Okay. So tell me about these magnets? Do they have a north and a south? |

| | |
|---|---|
| Students | Yeah. |
| Teacher | Is it on the same side? |
| Student | No. |
| Teacher | No? Who says they're different? *(Show of hands.)* If this side is north... if this side of the ring magnet is north what is the other side of it? |
| Student | South. |
| Teacher | So the ring magnet has a north and south? |
| Students | Yes. |
| Teacher | How do we know? |
| Jack | Because we tried it out. |
| Teacher | And? What did we discover? |
| Student | Magnets attract. |
| Teacher | Let Jack finish. |
| Jack | Because if you turn it around it won't attract and if you turn it around it'll attract. |
| Teacher | So it has a north and south? Yes it does. And is it all on the same side of the magnet? |
| Jack | No. |
| Teacher | No. One side of the magnet will be? |
| Jack | North. |
| Teacher | And the other side of the magnet will be? |
| Students | South. |
| Teacher | Right. And when we have two souths coming together they are going to? |
| Student | Um repel. |
| Teacher | Repel. If we have norths coming together they are going to? |
| Student | Repel. |
| Teacher | If we have a north and a south coming together they're going to? |
| Students | Attract. |
| Teacher | Attract. Just like the other magnets. |

Mrs. Montgomery's frequent and regular questioning guided and reinforced the students in their understanding of the rule of magnetism and how it applied to the ring magnets in this experiment.

The role that the teacher played in the students' explanation attempts was a critical one which cannot be explored fully by examining Table 5.5, a simple frequency count of the causal discourse features. More revealing information can be found in Table 5.6, which lists not only the temporal and causal relations which were constructed using the causal conjunctions in Table 5.5, but also the teacher's support in these constructions, indicated

**Table 5.6: The students' temporal and causal relations**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| X because Y | 1 | | 2 | | | | | | | | 3 |
| X because not Y | | | 1 | | | | | | | | 1 |
| not X because Y | | 1 | | 1 | | | | | | | 2 |
| not X because not Y | 2 | | | | | | | | | | 2 |
| X because X | | 2 | | | | | | | | | 2 |
| (X) because Y | 5 | 2 | 2 | | 2 | 4 | 7 | 4 | 1 | 12 | 39 |
| (X) because not Y | | 1 | | | | | | 1 | 1 | 1 | 4 |
| (not X) because Y | | 2 | | | 2 | | | | | 2 | 6 |
| (not X) because not Y | 3 | 3 | | | 2 | | | 2 | | | 10 |
| (X) because... | | | 1 | 1 | | | 1 | | | | 3 |
| (X) because X | | 2 | | | | | 2 | | | | 4 |
| (X) because of Y | | | | | 1 | | | | | | 1 |
| X because of Y | | | | | 2 | | | | | | 2 |
| X so Y | 2 | 2 | | | | | | | | | 4 |
| X so not Y | | | | | | | 2 | | | | 2 |
| (X) so Y | 1 | | | | | | | | | | 1 |
| (not X) so not Y | | | | | | | | 1 | | | 1 |
| do X so Y happens | 1 | | | | | | | | | | 1 |
| if X, then Y | 3 | 1 | | | 2 | | 3 | 1 | | 6 | 16 |
| if X, then not Y | | | | | 1 | | | | | 3 | 4 |
| if X... | | 1 | | | | | | | | | 1 |
| if X, (then Y) | | | | | | | | | | 1 | 1 |
| (if X), then Y | 1 | | | 1 | | 1 | 1 | 1 | 4 | 17 | 26 |
| (if X), then not Y | | | 1 | 1 | | | | | | | 1 |
| X when Y | | | | | | | | | | 1 | 1 |
| when X, then Y | | | | 1 | | | 3 | | 3 | 1 | 8 |
| when X, then not Y | | | | | | | | | 1 | | 1 |
| (when X), then Y | | | | | 1 | 1 | 3 | 3 | 12 | 6 | 26 |
| (when X), then not Y | | | | | | | | | 2 | | 2 |

Items in parentheses indicate another speaker.

by the parentheses. The data show that of the four main temporal and causal relations constructed in the data, efforts made entirely by the students accounted for only 50 of the 175 found (28.57%). In other words, the teacher directly supported the students in constructing these relations in 71.43 percent of the explanation attempts which used the four main causal language features. The most common forms of support were to ask a question demanding a *because* answer (67 out of 175; 38.29%) or to ask a question using an *if*-clause (27; 15.43%) or a *when*-clause (28; 16%) conditional construction requiring a short answer by the students.

Table 5.6 also shows that not all examples of *because* were in well-constructed explanations. A few (3; 1.71%) were aborted explanations (indicated by ellipses), in which a student attempted to respond to the teacher's question, but was unable to complete his or her ideas:

> Teacher: It doesn't have an N and it doesn't have an S. I wonder why?
> Student: Because...

There were six examples where students had the same or similar propositions on both sides of *because*, resulting in what could be considered a non-explanation. This happened twice when a student was attempting a full-sentence explanation (as in Example A) and four times when a student was responding to a question (as in Example B):

> Example A:
>
> Student: We think that the north and south are the strongest because we know that they are the strongest.
>
> Example B:
>
> Teacher: Why do you think it will change directions?
> Student: Because it's got a mix up the directions.

These "non-explanations" were not probed further; typically the students' efforts were accepted and other students were invited to offer explanations which would respond better to the teacher's questions.

As Table 5.5 shows, *make* was the only causal process used by the students, and it was used in constructions such as "I made it into a magnet" and "The ring magnet made it go around in circles." Mrs. Montgomery, however, used *create* on several occasions during

Experiment Seven, in which the students were "creating" a compass. These constructions included ones where the students were required to complete the sentence:

| | |
|---|---|
| Teacher: | Rub the needle across the magnet two hundred times. What are we creating when we're rubbing the needle? Cory?... When we're rubbing the needle what are we creating? We're creating a? |
| Students: | Magnet |

The teacher also used processes such as *turn something into something* and *cause,* but the students' causal processes remained limited to *make.*

## 5.3 Tracking the construction of three key concepts

As noted in section 5.1, Mrs. Montgomery chose to introduce and reinforce the vocabulary the students would need for each experiment, along with the day's procedure, at the beginning of each session just after she reviewed the previous day's experiment. This meant that unlike the situation in Mrs. Sinclair's class in which all words were defined on the first day of the unit, Mrs. Montgomery provided immediacy by first introducing the terms so that the students would be able to associate them directly to the experiment at hand, and then by reviewing and reinforcing them on each subsequent occasion where they were needed. Moreover, the experiments were ordered in a way which allowed the students to build an understanding of a concept and then build on that understanding by using it in combination with other related concepts which they were also learning. This can be seen clearly through the tracking of the four key concepts of *attract, repel, south pole,* and *north pole.*

### 5.3.1 Building up an understanding of *attract*

On the first day of the unit, Mrs. Montgomery told the students that they were going to use a wand magnet to "figure out which things the magnet... will attract." She then elicited a definition of *attract* from the students:

| | |
|---|---|
| Teacher: | Do we know what that word attract means? |
| Students: | No. |
| Teacher: | What does that word attract mean? |
| Hannah: | I think um... if the thing is made out of metal and you can... the there's a force that will pull it so it stays. |
| Teacher: | Good. It stays there. Hannah said an energy force... will pull it. |

| | |
|---|---|
| Student: | And you can stick it on the refrigerator and it will stay because it's cold. |
| Teacher: | You think these magnets can stick on our refrigerator because it is cold?... Well we're going to discover that. We're going to discover if it's because it's cold or if it's something else. |
| Student: | But we don't have a refrigerator. |
| Teacher: | Not here we don't. But we've got the magnet wand and this is all our experiment. So we're going to put our wand next to each one of these things. |

Hannah's definition offered a token/value relation, although the token was stated in Mrs. Montgomery's question rather than in Hannah's answer:

| | | |
|---|---|---|
| Attract | means | if the thing is made out of metal there's a force that will pull it so it stays. |
| token | rel:int | value |

Her response showed that she has a good grasp of what happens when a magnet wand and metal are placed together, so Mrs. Montgomery repeated her explanation for the class, but in a condensed version which more closely equated the technical term with an everyday term, also using a token/value relation. The teacher's construction also relied on a token stated in her earlier question:

| | | |
|---|---|---|
| Attract | means | it stays there. |
| token | rel:int | value |

The comment following Hannah's elaborated on this, offering an explanation attempt, but Mrs. Montgomery questioned this student's background knowledge, telling the students that they will be able to examine their ideas more fully over the unit. She then introduced the items which the students would test in the first experiment, eliciting the labels for each item and printing those labels, with hand-drawn representations of them, on chart paper on the wall.

Once all the items were labeled, Mrs. Montgomery told the students what they were going to do with them, using both the target term *attract* and the everyday term, *pull toward,* which Hannah had introduced:

| | |
|---|---|
| Teacher: | This is your job... Your want to find all the things that **are attracted to** the magnet. |
| Students: | Oh. |
| Teacher: | All the items that **are pulled towards** the magnet. So there's |

| | |
|---|---|
| Student: | Energy? |
| Teacher: | There's an energy. That's right. Some things won't and some of the things will. |

By choosing to repeat the sentence but with a translation of the technical term into everyday words (note the boldfaced phrases above), and by choosing the everyday *pull towards* rather than *stay* or *stick,* which had also been mentioned earlier, Mrs. Montgomery was able to introduce the idea that the concept of *attract* goes beyond two items being in a state of togetherness, that it more closely involves a process of coming together.

After using *are pulled towards* to gloss the meaning of *are attracted to,* the teacher shifted back to a consistent use of the technical term as she directed the students to sort out the items according to which were and were not attracted. She also told them to think about why:

| | |
|---|---|
| Teacher: | I want you thinking about what things are attracted to the magnets... and why. What is similar about all these things? |

This experiment, done as Station One in Mrs. Sinclair's class, allows the students to experience the phenomenon of attraction and non-attraction as well as requires them to classify items based on their experiences. Just as in Mrs. Sinclair's class, some of the items challenged the students' everyday taxonomies, causing them to question what they considered to be metal, and whether all metals are attracted to magnets:

| | |
|---|---|
| Abby: | Hey it doesn't. |
| Teacher: | It doesn't. Why doesn't the key... what do you think Janie? |
| Janie: | It doesn't. That key's small. |
| Teacher: | It's because it's too small? Why do you think Abby? Why do you think it doesn't... why do you think it isn't attracted? |
| Abby: | Mm... it doesn't attract. I don't know. Maybe it's not metal. |
| Teacher: | Maybe it's not metal. |
| Abby: | It doesn't stick. |
| Teacher: | Is that not metal? |
| Abby: | No... maybe? I think? Yeah. I just think that not metal. It looks like metal. |

The experience of doing the experiment not only forced the students to question their judgement of what metal is, as Abby is doing in the excerpt above, but it also helped build up the concept of *attract,* a process which the students began to realize only occurs with certain types of metal for reasons that they were unsure of and offered different reasons for (e.g., Janie's suggestion that size affects attraction). In the final whole-class discussion of this experiment, however, the consensus was that *some* metals were attracted to the magnet, but not all. The students discovered, therefore, that the term *attract* has certain limitations, just as the students in Mrs. Sinclair's class did, but in this class, their conclusions were made public in the whole-class context and reinforced over the next few classes.

On the second day of the unit, the teacher reviewed the word *attract* by asking again which items were attracted and which were not, and why. Once again, she reinforced the idea that magnets attract some but not all metals. In Experiment Two, the students discovered which parts of the magnet were responsible for this attraction:

> Tanya: Maybe the magnet only works at the end and not in the middle because the pins are only attracted to the sides.
> Teacher: It has to go to the sides... why did you say it has to go to the sides?
> Tanya: Because uh... there's more power there?

Tanya's comment shows that she used her observations to construct her conclusion; in other words, she saw that the pins were only attracted to the sides, or ends, of the magnets, so she concluded that the magnet might only work on the sides or ends. Mrs. Montgomery, however, was not looking for *evidence* of where the magnet "works,' but instead the *reason* it only works in those areas. When Tanya sensed this, she shifted the function of *because* from one offering evidence to one offering reason: Because there's more power there.

This second experiment, therefore, helped build up the concept of attraction by showing how only certain areas of the magnet can attract and speculating on why. Each subsequent experiment constructed a deeper understanding of *attract.* Although Experiment Three did not use *attract* explicitly, the students experienced how paper clips formed a chain through attraction. Experiment Five was similar to Three, but it used magnetic marbles to form the chain. In this later session, Mrs. Montgomery again reviewed the meaning of *attract,* allowing the students to use the everyday term only to translate *attract,* but warned them that they needed to use "the science word." The goal of Experiment Five, she said, was to learn "how many of these magnets can be attracted to each other."

As mentioned above, in the first lesson, the term *force* was suggested by Hannah as something magnets have which allows them to stay in place. In Experiment Four, Mrs. Montgomery brought back this term by relating *attraction* to the force of magnetism. She did this by setting up the experiment at the front of the room and asking students to predict the outcome:

| | |
|---|---|
| Teacher: | Now we want to know if... the magnet will still attract that paper clip under the glass. |
| Students: | Yeah. |
| Teacher: | Predictions. Yes or no. Hands up if you think yes it will... So you think yes the magnet— the force of magnetism will go through the glass and attract the paper clip. |
| Student: | Yeah. |
| Student: | No. |

Mrs. Montgomery then performed the experiment with the glass, asking if the force of magnetism went through it. She then told students that they will do the same test with a variety of other items. She stated

> We're looking at magnetism... The force of it traveling through things. Not just being attracted to it but traveling through other materials.

In this experiment, the attraction of the safety pin on the other side of the glass was the proof which showed that the magnetic force had traveled though items such as glass, wood, paper, and plastic. The concept of attraction was consequentially expanded through this experiment to refer to a process which can occur through various materials and which is considered a force; *attract* is therefore not simply a process equivalent to *stick,* because there was no "sticking" involved in the experiment.

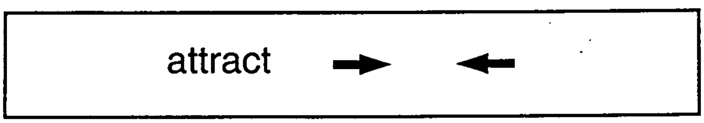
This use of a reaction, such as the safety pin being held up in mid-air on the other side of the glass, to offer proof that something has happened (e.g., the force is passing through the glass) also occurs in Experiments Six and Seven. In order to determine whether the force of magnetism (i.e., the ability to attract) had passed from the bar magnet to a nail or pin which has been rubbed on the bar magnet several times, the students needed to test the nail to see if it acquired the power to attract. The students also needed a basic understanding of *attract* to speculate about why their homemade compass spun around to face north. By this stage of the unit, therefore, they were not only continuing to build up their concept of *attraction,* they were using their understanding to offer proof that the experiment they were carrying out actually worked.

Throughout the experiments, Mrs. Montgomery was careful to make sure that the students used the term *attract* to capture the meaning of what the students were experiencing, and she frequently reminded the students that scientists use science words. She rejected words such as *stick* or *work* in their explanations and observations. At times, however, she asked students what *attract* meant and allowed them to use their everyday terms to translate the term, quickly reminding them of the preferred term:

Teacher: What does attract mean?
Student: Stick to the metal.
Teacher: Yes but we don't use that word stick anymore. Do we?
Student: It attracted.
Teacher: Scientists use the word attract. They use science language. And that's what we're learning is science language.

Yet this type of translation and the multiple experiences of attraction were not the only methods which Mrs. Montgomery used to help the students construct the meaning of *attract*. While contrasting the term with *repel* in experiment nine (see section 5.3.2 for a discussion of *repel*), she matched it to a hand-drawn representation which she displayed on chart paper, as shown in Figure 5.1

**Figure 5.1: Visualizing *attract***




She immediately reinforced this visual graphic by having the students act it out physically:

Teacher: Things that attract. Let's do it with our hands. Take your hands and make your hands attract to each other. What will they look like? *(Students clap their hands together and keep them together.)* And if they were magnets can we pull them apart?
Students: No.

Throughout the ten experiments, therefore, Mrs. Montgomery used four distinct methods to help the students build up the concept of *attract:* translation between the technical term and the everyday term, visual graphic representation, physical representation through action, and experience through manipulation of the magnets in the experiments. The first three methods concerned the renaming, redefining, and reclassifying of the concepts, and the fourth involved all of these as well as provided the opportunity to reason and explain. Mrs. Montgomery also insisted that the students use the technical term which encompassed the concept. Moreover, for the teacher, the ordering of the experiments was key in that she realized the students needed to have a good grasp of the concept of attraction so that they could use this understanding to construct further knowledge about magnetism, including the concept of repulsion.

### 5.3.2 Building up an understanding of *repel*

The term *repel* and the experiences associated with it did not arise until the ninth class of the unit, in which the students were to place the ends of the magnets together to determine the rule of magnetism, or which ends attract and which ends repel. Throughout the first eight experiments, Mrs. Montgomery focused on building up the concepts of attract (section 5.3.1) and north and south poles (section 5.3.3). It was particularly important that the students have a solid understanding of *attract* because this process was to be used as an anchor with which to define *repel.* Just as she did with *attract,* Mrs. Montgomery used four distinct methods to construct the concept of *repel:* through diagrams, through words, through physical action, and through experience. The first three methods explicitly contrasted *repel* with *attract* and were used prior to having the students experience the concept in the experiments.

At the beginning of Experiment Nine, Mrs. Montgomery told the students they were going to learn a new word. This new word was associated with *attract* from the onset:

| | |
|---|---|
| Teacher: | You're going to take your two bar magnets... and you're going to experiment with them because your job is to find out... what two ends attract... and I'm going to teach you a new word today. |
| Students: | A new word. |
| Teacher: | A new word. You're going to look at attract. *(She writes the word on chart paper.)* |
| Students: | Attract. |
| Teacher: | That means come together... And the new word today is repel. |
| Student: | Repel? |

Teacher: Watch my diagram for repel. *(She starts to draw on the chart paper. See Figure 5.2.)*
Student: Repel.
Teacher: And tell me if you know what it means by looking at my diagram.

**Figure 5.2: The graphic representation of the two key processes**

attract → ←
repel ← →

The students already had a good understanding of *attract* because they had been working with the concept over the past eight experiments. The drawing related the two processes as opposites, which elicited a few related responses:

Student 1: They're no... attracting.
Student 2: Not attract.
Student 3: Take it out.
Student 4: Not attracted.
Student 5: Taking it out.
Vic: Um when you put it on the table it will not stick.

All students constructed a token/value relationship, although without articulating the token. Only Vic offered an elaborated value, using a *when*-clause to help define the term:

| | | |
|---|---|---|
| Repel | means | when you put it on the table it will not stick. |
| token | rel:int | value |

The core of his definition, though, remained consistent with those of Students 1, 2, and 4 in that it offered a negative as the opposite of *attract*. Students 3 and 5, on the other hand, did not offer a simple negative, but tried to create a different kind of opposite, based on the visual representation Mrs. Montgomery had drawn on the chart paper.

Mrs. Montgomery acknowledged all these efforts but pushed the idea beyond the negative of *attract* towards the idea which Students 3 and 5 were suggesting. She did this by having the students act out both *attract* and *repel* with their hands. Whereas with *attract* the students responded that they could not pull their hands apart, they showed that when their hands were repelling, they could not force them together. This physical acting out of the two processes aimed to show that the two processes were opposite, but not simply negatives of each other. The students did this physical acting out at the beginning of both experiment nine and ten to reinforce the idea of *repel* as something different from *not attract.*

Once *repel* had been presented in a visual graphic format, defined linguistically by contrasting it with *attract* (as shown by the students' responses above), and constructed further through physical action, the students began their experiment in which the force of repulsion could be experienced. They commented excitedly about how one north end would "chase" another north end on the table, and how one end would "push them out." During the experiments, the teachers prompted students to use the new word to talk about what they were experiencing:

| | |
|---|---|
| Student: | It pushes it away. |
| Vic: | It turns right away. |
| Teacher2: | It does. It does not attract. We learned a new word for that Vic. Can you remember? |
| Vic: | Attract? |
| Teacher2: | This attracts. *(She puts the north pole and south pole together.)* |
| Vic: | Repel? |
| Teacher2: | Yes. You showed us what it was. |

Just as with *attract,* the teachers expected the students to use "the science word" and frequently modeled it themselves when talking with the students.

Once the students had discovered the rule of magnetism in Experiment Nine, Mrs. Montgomery reinforced the use of *repel* and *attract* by showing them a broken magnet and having them speculate about which end was the north pole and which was the south by showing them which ends attracted and which repelled. She acted out *attract* and *repel* with the pieces of the broken magnet in her hands, just as she had asked the students to do in the earlier physical activity, emphasizing how hard it was to push the same poles together when they were repelling. To make an educated guess about this, the students needed to understand not only the concepts of *attract* and *repel,* but also the poles and the rule of magnetism. This understanding was also needed for the final experiment, which required students to explain why one ring magnet appeared to float over another. To offer an explanation, the students needed to have built up an understanding of repulsion which would allow them to see that the floating was a result of two alike poles repelling.

The ordering of the experiments offered the students a basic understanding of *attract,* which was then used to help define *repel* in the final two experiments. Mrs. Montgomery tried to make sure, however, that the students did not simply equate *repel* with the negative of *attract.* She did this primarily by using physical action and experience, but she also did this by combining the four key terms needed to explain magnetism. *Attract* helped define *repel,* but the poles also played a key role in constructing the meaning of *repel* as well as further constructing *attract.* In other words, by the last two experiments, Mrs. Montgomery had succeeded in building up a knowledge base which was sufficient enough to begin interlocking the definitions without worrying that students would be confused. This ordering of the experiments and her attention to the "science words" appeared to be key in helping her do this. She was able to guide the students to an understanding of the term *repel,* and then have the students use the term to reason and explain what they saw happening in the experiments.

### 5.3.3 Building up an understanding of *north pole* and *south pole*

As noted in chapter four, the goal of the magnet unit with regards to magnetic polarity was to make students aware that magnets have a north pole and a south pole and to suggest a comparison between magnets and the earth ("a big magnet"). Whereas in Mrs. Sinclair's class there seemed to be a mismatch between the students' token/value relation and the instructional carrier/attribute structure, where the written instructions used a possessive relation and Mrs. Sinclair used an intensive one, the students in Mrs. Montgomery's class appeared to maintain the possessive relation throughout the experiments. The magnets which were used in this class did not have different colors painted on the ends, but in Experiment Two, when the concept of north and south poles was first introduced, Mrs. Montgomery brought the students' attention to the *N* and the *S* printed on the bar magnets:

Teacher: Now on your bar magnet there are two letters.
Student: S N.
Teacher: An S… and an N. I wonder what they stand for.
Student: North.

Mrs. Montgomery then made a connection between the *S* and the *N* on the magnets and directions, which she assumed some of the students may have studied earlier, but checked her assumptions to make sure:

| | |
|---|---|
| Teacher: | Have you studied directions at all? North south east west? How many of you have heard of those words north south east west?... *(Very few raise their hands.)* How many of you know... the word north?... *(Few.)* Right. How many of you have heard the word south?... *(Few.)* Okay now I want you to listen to the words. Nnnnnorth. What letter does it belong to? |
| Students: | N. |
| Teacher: | Could it be— |
| Student: | That's north. |
| Student: | North and south. |
| Teacher: | You're right. That's north. |
| Student: | And then that's the other one is south. |
| Teacher: | Oh very good. That's very good. |
| Student: | So magnets have a north and a south. |
| Teacher: | Right. It has an N for north... and S for sss |
| Students: | South. |
| Teacher: | Can you say that? [North... south. |
| Students: | [North... south. |

She then continued the lesson by telling the students what they will do in that day's experiment.

What is interesting about this introduction to the poles is the move from the specific, which Mrs. Montgomery began with when she used an existential process to bring the students' attention to the letters on their bar magnets, to the generic comment made by a student after the connection between the poles and directions had been made:

| | | |
|---|---|---|
| Now on your bar magnet | there are | two letters. |
| part:spec (circ.) | exist | existent:spec (part.) |

| | | |
|---|---|---|
| So magnets | have | a north and a south. |
| carrier:gen (part.) | rel:poss | attribute:gen (part.) |

By showing the students that there was an *S* and an *N* on the magnets, then by giving them the words for these letters and connecting them to directions, Mrs. Montgomery guided the students to the understanding that magnets have a north and a south, a very different construction from the carrier/attribute relation Mrs. Sinclair had attempted in her class.

The use of the possessive relation became the anchor to help construct meaning for the poles as well as to deepen the students' understanding of *attract* and *repel.* This was done by building up a taxonomy of magnet types and by bringing to the students' attention the observation that the ring magnet did not have an *S* and an *N* printed on it, a fact that became an issue in the class: If all magnets have a north pole and a south pole, where are the poles on the ring magnet? Mrs. Montgomery began asking this question during Experiment Three, and repeated in during Experiment Eight, where ring magnets were also used, and at the end of Experiment Nine in preparation for Experiment Ten, where the students would need to address this question directly.

In Experiment Nine, the students placed the poles of the magnets near each other to witness the reaction which took place, and from this, discovered the rule of magnetism—alike poles repel and different poles attract. To do this, however, the students needed to understand the concepts of *repel* and *attract* as well as to identify the poles on the magnet. All four terms, therefore, interrelated in this experiment.

In Experiment Ten, the students used their understanding of the rule of magnetism to determine that the ring magnet, like other magnets, must also have these two poles. The students also discovered through this experiment that the poles were located on the sides of the ring magnet. They were led to this understanding during the experiment by the teachers' use of conditional structures:

| | |
|---|---|
| Teacher: | Now if you've got a north on the bottom of this... |
| Student: | A north? |
| Teacher: | If this is north on the bottom magnet... what's the top of that magnet? |
| Student: | ... A south. |
| Teacher: | Right. Right. Why do you know that?... What do you know about north and south? |
| Student: | Mm... I don't know. |
| Teacher: | North and south. When you put them together? |
| Student: | They will... attract. When you put both north and north then... it repels. |
| Teacher: | *(Pointing to the student's diagram of repel.)* Then that's that one right? |
| Student: | Yeah. |

To figure out where the poles on a ring magnet were located, the students needed to understand the concepts of attract and repel as well as know the rule of magnetism. By seeing how the two ring magnets reacted, the students could reason which poles were facing which other poles. In other words, by Experiment Ten, the students had labels for the four concepts and were able to relate them together to explain what they were witnessing. This was accomplished because the ordering of the experiments allowed Mrs. Montgomery to build up the concepts to a point where they could be interrelated so that the students could explain what they were seeing. Moreover, Mrs. Montgomery's attention to the correct labeling of the concepts allowed the students to feel comfortable using the technical terms in their explanations.

## 5.4 The language of the interviews

After the ten experiments and the writing exercises had been done, six students, chosen for their lack of shyness to talk to the researcher (see Chapter 3), were interviewed about their understanding of magnetism. The questions were asked by the researcher, one on one, in Mrs. Montgomery's office, and focused on what the students remembered most ("What did you learn about magnets?" and "What was your favorite experiment?"), what the rule of magnetism was, and how they made a compass. Other questions which aimed to probe the responses further were asked at times in response to the students' answers.

### 5.4.1 The students' use of technicality

All six students frequently used the language which Mrs. Montgomery had set out to teach, although as Table 5.7 shows, they also used other processes to construct their explanations. Just as in the ten experiments, *attract* was the most popular process used to explain what magnets "do" to other objects, accounting for approximately one third of all processes used in the explanations (42; 39.25%). *Repel* (16; 14.95%) was chosen over *push away* (1; .93%) or *push out* (2: 1.87%), but it was still dropped on seven occasions in favor of *doesn't attract*. Yet when asked if the two alike poles didn't attract or if it was something else which happened, all but one student interviewed said that there was something else happening beyond not attracting. The only student who did not say this had become confused by the question and had instead gone on to describe a different experiment.

**Table 5.7: Processes used to talk about magnetism in the interviews**

| Process | Times | Process | Times | Process | Times |
|---|---|---|---|---|---|
| attract | 42 | go out | 1 | push away | 1 |
| come together | 3 | go together | 2 | push each other out | 2 |
| do something different | 2 | go up | 1 | repel | 16 |
| face | 2 | hold | 1 | spin | 2 |
| fly | 1 | like | 1 | stick | 9 |
| follow | 1 | move | 9 | turn around | 2 |
| go | 5 | point | 3 | work | 1 |

What was also noticeable in the data was the use of the participants *north* and *south.* Whereas the students in Mrs. Sinclair's class preferred the observable characteristics of *grey* and *red,* these terms were never made available to Mrs. Montgomery's students because the magnets chosen did not have colors; only *N* and *S* were etched into the appropriate poles. With the use of *north, south, attract,* and *repel,* when the students explained the rule of magnetism in the interviews, their explanations sounded much more scientific:

Jack: We um used the north and north but it... didn't attract. Then we used south and south but it didn't attract. But north and south attracts.

Barbie: North and north doesn't go together because it's the same but if north and south go together because it's not the same. They will attract.

Hannah: If you put north with north... repel. If south and south again repel. North and south... attracts. South and north attracts.

These students did not rely on exophoric expressions such as *here, there,* or *this* in their explanations. This was not the first time they had participated in context-reduced discussions about the rule of magnetism; indeed they had already discussed their experiments and completed writing activities which had helped them move away from the type of context-dependent talk exhibited by the students in Mrs. Sinclair's class.

### 5.4.2 The use of causal discourse in logical reasoning

The causal language features used by the six students in the interviews are summarized in Table 5.8, along with the frequencies of these items. As the table shows, *because* is the most popular causal resource used by the students, reflecting the *why*-questions frequently asked by the researcher. In fact, out of the 28 examples of *because*, 20 (71.43%) were framed by the interview questions in exchanges such as the following:

| | |
|---|---|
| Researcher: | When you used a bar magnet and a needle... why did you rub the needle on the bar magnet two hundred times? |
| Jack: | Because then it can make it move. |

The conditional constructions using *when... then...* and *if... then...*, however, were more often fully constructed by the students. Out of 20 temporal (*when... then...*) relations, the researcher framed only seven constructions (35%). Out of the 22 causal (*if... then...*) relations, only eight (36.37%) were set up by the researcher. Whereas the higher frequency of teacher-led *because* responses reflects the findings from the ten experiments, the lower number of teacher-led conditional constructions represents a dramatic shift. One reason for this could be that the one-on-one format of the interviews allowed—or even pressured—the students to offer extended discourse wherever they could. Yet these constructions typically came across as confident statements of what the students understood:

| | |
|---|---|
| Researcher: | Now do you remember how to make a compass? |
| Barbie: | Yeah like... you put the... you get a compass and you put it on the side. Then you put a you rub the... needle til... um one hundred times. Then you put the needle on the cork that... the cork has been put in the bowl of water and it'll actually point to the north end. But if you use the bar magnet and turn it around it will like turn around. And... if you use the like the big bar magnet near the... compass it will like been turned around and been... showed to the north or the south... or somewhere else. |

It would appear from an examination of the interview data that the increase in examples where the students offered a full explanation rather than completing sentences for the researcher reflects a greater ability on the part of the students to explain themselves.

**Table 5.8: Causal language features and their relations in the interviews**

| Language Features | no. of times |
|---|---|
| **TIME conjunctions** | |
| and | 13 |
| and then | 15 |
| then | 12 |
| until | 1 |
| still | 4 |
| already | 1 |
| when… then… | 20 |
| **TIME circumstances** | |
| in a few days | 1 |
| **PLACE circumstances** | 35 |
| **CAUSE conjunctions** | |
| because | 26+1* |
| so | 3 |
| if… then… | 22 |
| **CAUSE processes** | |
| make (X) | 2 |
| make (X do Y) | 2 |
| **CAUSE circumstances** | |
| because of | 1 |
| **NOMINALIZATIONS** | |
| magnetism | 1 |
| our jumping | 1 |
| the attract one | 1 |
| the repel one | 1 |
| **PASSIVE VOICE** | 5 |
| **LEXICAL DENSITY** | 39.5 |

| Temporal and causal relations | no. of times |
|---|---|
| **MORE CONGRUENT FORMS** | |
| X because Y | 3 |
| X because not Y | 1 |
| not X because Y | 3 |
| (X) because Y | 13 |
| (not X) because Y | 3 |
| (not X) because not Y | 3 |
| (X) because… | 1 |
| X so Y | 3 |
| when X, then Y | 11 |
| when X, then not Y | 2 |
| (when X), then Y | 5 |
| (when X), then not Y | 2 |
| if X, then Y | 12 |
| if X, then not Y | 1 |
| if not X, then Y | 1 |
| (if X), then Y | 7 |
| (if X), then not Y | 1 |
| you do X and Y happens | 3 |
| **LESS CONGRUENT FORMS** | |
| X because of Y | 1 |
| X to do Y | 1 |
| X makes Y | 2 |
| X makes Y happen | 2 |

Items marked with an * indicate aborted attempts at explaining (i.e., unfinished thoughts)

Table 5.8 also reveals that the students' only causal process used was *make*. This was used twice to construct the meaning *cause something to exist,* such as in the following example:

Trish: Sometimes when you break the magnet apart? You can make two different magnets.

Trish also used *make* in the sense of *cause something to do something* when she speculated on why the magnet was not able to attract a penny:

| | |
|---|---|
| Trish: | It is metal but like kind of underneath it is something that... makes... the magnet not like be... not... make it be able to... uh attract. |

There were, however, other processes used in actions which strongly suggested causality. Hannah used *push away* in this sense when she described what had happened in the experiment with the "flying" ring magnet:

| | |
|---|---|
| Hannah: | If it was south to south... it was like flying! |
| Researcher: | It was like flying off the pencil. Mm-hmm? |
| Hannah: | And it mm when it was north and north like... when it was north and north it did the same thing. And poof! |
| Researcher: | Why did it do that? |
| Hannah: | Because it was uh... because the magnetism is pushing away from each other. |
| Researcher: | Mm-hmm? That's right. It's repelling. |

Hannah inferred that it was magnetism which caused the ring magnets to repel or push away from each other.

Barbie also created a strong sense of causality when she used processes in actions. For example, she explained that one has to rub a needle on a bar magnet

> because it's making a little electricity that will force... some of the... like the... energy in the needle and then... then it will show... probably show the in the north way.

Rubbing causes electricity, according to Barbie, and the electricity causes energy to go "in the needle" which will result in a particular event: The needle will point north. When asked why the bar magnet is able to move the compass needle around, Barbie explained that it has something in it which gives it this ability when you hold it near:

| | |
|---|---|
| Barbie: | The big bar magnet got a metal in it and then it can move the... needle around. |

In other words, the metal in the bar magnet acts on the needle, causing it to move around.

The language of the students suggested that they were thinking critically about cause-and-effect relations, even if they were not always correct about them. For example, when asked what caused the needle to point north, Hannah replied "the Earth." When this was probed further, her conception was revealed:

| | |
|---|---|
| Researcher: | What makes it turn around to face north? |
| Hannah: | The Earth. |

| | |
|---|---|
| Researcher: | The Earth. Why does the Earth do that? |
| Hannah: | Because it's facing north. |
| Researcher: | The Earth is facing north? |
| Hannah: | ... The Earth is turning... has gravity. And the gravity can... when we jump the gravity... our jumping pushes up but the gravity pushes down. |
| Researcher: | Right. So you come down to Earth again. Right. And what does that have to do with the magnet and the compass? |
| Hannah: | Um... compasses show you the way through the forest... and flashlights just shine... through the forest to see. |

Hannah's argument broke down because her connections to gravity led her in new directions. The researcher tried to bring that focus back by asking what the connections were, but in the last exchange above, Hannah picked up on the word *compass* alone and elaborated on that instead of connecting compasses with magnets.

Being able to discover the students' causal agent in their explanations helped reveal their understanding of the concepts, which at times was quite dynamic. Jack, for example, believed that the bar magnet played a role in creating a causal agent which could be used in another relation, but his reasoning consistently returned to the compass itself as the agent:

| | |
|---|---|
| Jack: | And then you have to rub it two hundred times. Then you put it on the ca cork. Then you put it on a compass... then it will move to south. |
| Researcher: | And what makes the needle move? |
| Jack: | Um the... compass. They go to the same direction as always. |
| Researcher: | I see. And what directions do compasses go in? |
| Jack: | North. |
| Researcher: | North. Right. It points north. And what does that have to do with magnetism? |
| Jack: | Um... uh... um... I don't know. |
| Researcher: | When you used a bar magnet and a needle... why did you rub the needle on the bar magnet two hundred times? |
| Jack: | Because then it can make it move. |
| Researcher; | The needle? |
| Jack: | Yeah. And then compass will move then and the needle will move too. |
| Researcher: | I see. Okay. And why does the needle spin? |
| Jack: | Because of the uh... because of the compass. |

Jack seemed to know that rubbing the needle on the bar magnet played a key role in the needle's turning, but his responses suggested that he was still not certain about the connections between the compass and magnetism. This breakdown on content understanding could only be probed through the use of causal language.

Aaron's understanding of magnetism and compasses seemed much less clear than Jack's. Although his English appeared more limited in his ability to find correct labels and to talk in extended texts, with the help of the researcher's questions, he had little difficulty constructing a recount of how to make a compass:

| | |
|---|---|
| Researcher: | Do you remember what you did to make a compass? |
| Aaron: | Oh I know I know. You put uh... the you get the water right?... And we had a magnet... what's the stuff when you with the water? |
| Researcher: | That you put in the water? That's a piece of cork. |
| Aaron: | Cork. Then we... let's see if it goes straight like... to north. |
| Researcher: | Mm-hmm? And how did you do that?... You used a needle... and... |
| Aaron: | A pin. |
| Researcher: | And... you had to do something with the needle. Do you remember? |
| Aaron: | ... Oh the big bar magnet. |
| Researcher: | Right... How many times did you rub that needle on— |
| Aaron: | Two hundred. |
| Researcher: | Two hundred. And then what did you do with the needle? |
| Aaron: | Put it in the water. |
| Researcher: | In the water or on the cork? |
| Aaron: | On the cork. |
| Researcher: | And what happened? |
| Aaron: | ... Mm uh... it went. |
| Researcher: | It went? Where? |
| Aaron: | In the water. |
| Researcher: | It turned around? Right? And what way did it turn? |
| Aaron: | South. North. West. East. |

Yet when the researcher asked why the needle had turned, Aaron's understanding broke down:

| | |
|---|---|
| Researcher: | Right. And why do you think it did that? |
| Aaron: | ... ... Because a cork— ih is a cork a magnet? |
| Researcher: | No. |
| Aaron: | Because the cork is not a magnet. |

When the researcher asked what was a magnet, Aaron thought briefly about the question and responded by saying that the needle was. Aaron's performance suggested that with teacher help, he could recount his experiments fairly well with his current linguistic resources, but his ability to reason needed continued development. In particular, rather than saying what the cork was not, he would have offered a better explanation had he stated what the needle was.

The students who could use a variety of causal language features well provided text which not only offered clear windows to their understanding, but also showed that they were thinking critically about what they were learning and attempting deeper connections, even if their language was not grammatically correct and the connections were at times odd. Efforts at grammatical metaphor were rare, as Table 5.8 shows, yet the limited examples which surfaced were in the explanations offered by students who gave evidence that they understood the concepts well. An example of this shows one student—Barbie—using nominalization to help her explain the difference between *not attract* and *repel:*

| | |
|---|---|
| Researcher: | Now… you mentioned that magnets don't attract wood and they don't attract paper… and the same ends of a magnet repel. Can you tell me what the difference is between repelling and not attracting? |
| Barbie: | Oh um if it repels. Oh. That part's a hard one. |
| Researcher: | That's a pretty hard question isn't it?… Well what happens if you take a wand magnet for example or the the north end of a bar magnet and you put it next to a piece of paper… what happens? |
| Barbie: | It it repels? |
| Researcher: | Does it repel? |
| Barbie: | Uh **it doesn't attract?** |
| Researcher: | It doesn't attract. But if you put a north end of a magnet next to a north end of a magnet… what happens? |
| Barbie: | **It repels.** |
| Researcher: | It repels. And what's the difference? |
| Barbie: | Um… the attract one… actually **the not attract one** if… it doesn't push each other out and **the repel one** push each other out. |

Barbie took her two congruent responses of "it doesn't attract" and "it repels" and nominalized them into "the not attract one" and "the repel one," making it easy for her to offer clear, concise definitions. Moreover, the exchange between Barbie and the researcher revealed that Barbie understood these concepts well.

Whereas the students in Mrs. Sinclair's class generally appeared to have trouble articulating novel explanations of ideas, Barbie's definitions above suggest that even though she was an ESL student making grammatical errors, she could clearly articulate her ideas. This seemed to be the case for all of Mrs. Montgomery's students who offered extended discourse in the interviews, with the notable exceptions above. An ability to articulate clearly the causal and temporal relations was illustrated in the following analysis of relations in Trish's explanation of what happens when a magnet breaks in half:

> Trish: Like when a magnet falls on the floor and you pick it up and you find it... broken? Um it can't come back together again because it will repel. It— the broken pieces. And it will repel because... um the north side? If the north side broke it wouldn't... um and you turned it around with the other one? And you sticked it together it... it's would... wouldn't come together.

Trish's line of argument based on the causal and temporal relations she constructed developed as "When X, then not Y because Z. Z because if A (which is part of X), then not Y." In this argument structure, X refers to the three pieces of information in the first sentence: The magnet falls on the floor, you pick it up, and notice it's broken. The proposition Y refers to "it can't come back together," and Z is "it will repel." Trish restructured and repeated her argument in the second part of her text, stating that Z (the repelling) will happen because if A ("if the north side is broken," which reflects back to the broken magnet of X), then not Y ("wouldn't come together" equates to "it can't come back together"). Although Trish repeated herself, used a great deal of coordination ("and"), and had to clarify that "it" meant "the broken pieces," her explanation was still much clearer and closer to acceptable written scientific text than many generated by Mrs. Sinclair's students.

## 5.5 Summary

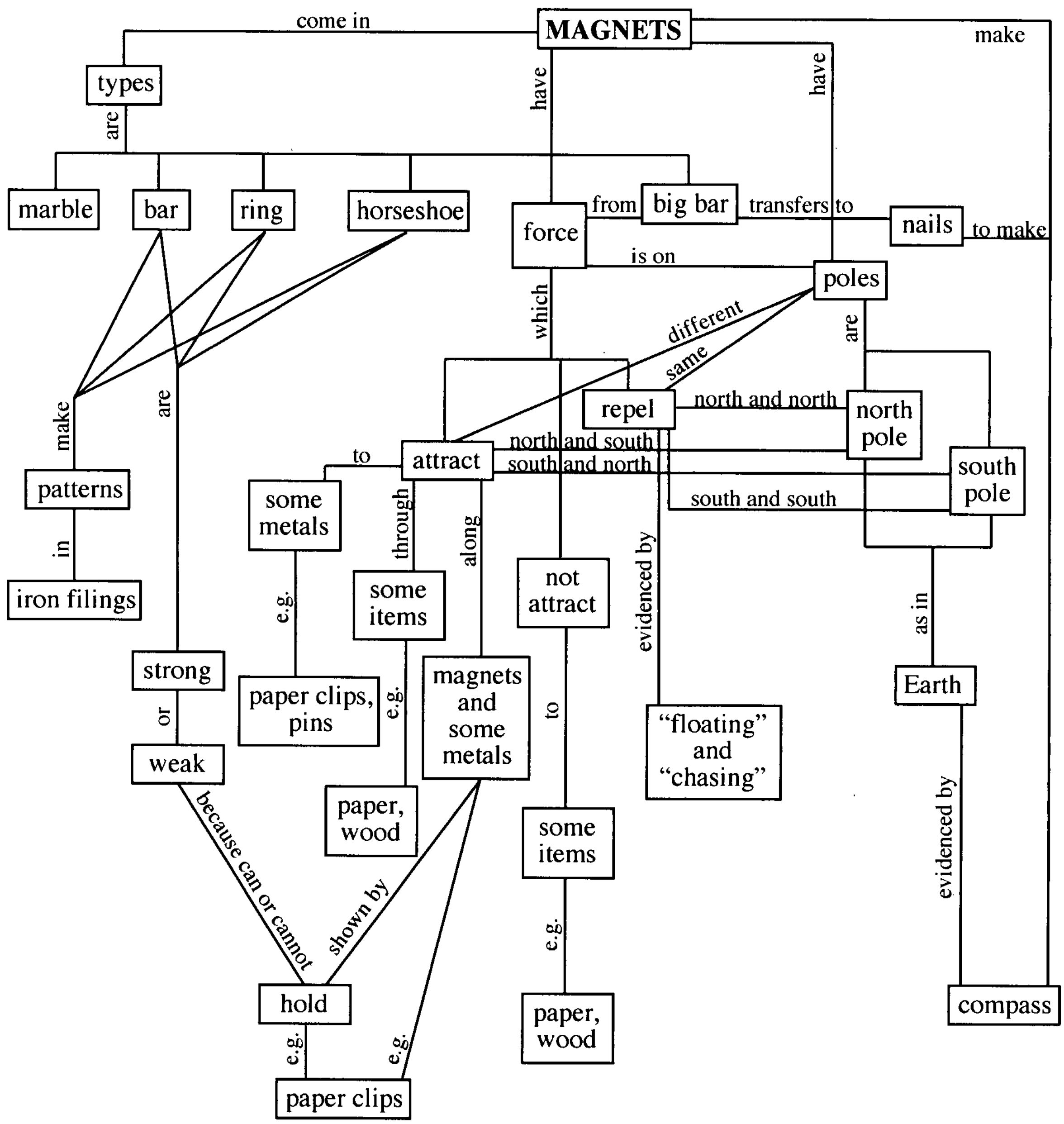
Chapter 5 provided a detailed look at how Mrs. Montgomery helped her students construct an understanding of magnetism. When she introduced the materials and the concepts, she spent time making sure the students had labels for all the participants and processes. This labeling was done in a variety of ways: by showing students the participants and making sure they had the labels for the items, by showing students a graphic representation of a process, by having students physically act out the process, by translating between everyday and technical terms, and by guiding students in their experiments of the processes through participating in the hands-on experiments. Mrs. Montgomery elicited definitions and helped define terms equating an everyday term with a technical term, but insisted that the students use the "science words." The unit also required students to create taxonomies of items that are and are not attracted, and magnet types.

The unit in Mrs. Montgomery's class was organized in a way which helped the students slowly build up deeper understandings of the concepts they were learning. Moreover, the magnets had *N* and *S* imprinted on them instead of color coding, which forced the students to associate the ends of the magnets with the directions *north* and *south* rather than with colors, as Mrs. Sinclair's students had done. The key vocabulary was revisited, reviewed, and emphasized throughout the unit. By the end of the unit, the students seemed to be able to use the concepts they had learned—with the appropriate technical labels—to reason and explain what they were experiencing. The concept map created through the discourse of the classroom (following Novak, 1998) is captured in Figure 5.3. This concept map was qualitatively and quantitatively different from the one created in Mrs. Sinclair's class, representing different knowledge.

As in Mrs. Sinclair's class, the students in Mrs. Montgomery's class also had trouble choosing an appropriate actor for the process *attract*. Most often, they chose as the actor to use the item which was being attracted, suggesting that this part of the concept may have been either difficult to grasp or perhaps not an important distinction for the students to make. Moreover, just as in Mrs. Sinclair's class but to a lesser extent, the students here gave human qualities to the actor or the magnetic processes, commenting, for example, that the magnets repelled because they "hate each other." In Mrs. Montgomery's class, however, the teachers appeared to put a larger emphasis than did Mrs. Sinclair on having the students use the appropriate science terminology to explain and reason.

Regarding the causal language features which the students used to explain their understanding in the class interactions, *because* was the most common (76), followed by *if*-clauses (51), then *when*-clauses (38). The use of *so* was infrequent (9). The number of teacher's questions which asked *why* (128) or *what happens* (125) likely had a role in these numbers, as suggested by the number of responses made by the students because of direct

**Figure 5.3: Mrs. Montgomery's unit as a concept map**




support or questioning by the teacher. As noted in Section 5.3.2, efforts made entirely by the students to explain using the four main temporal and causal relations accounted for only 50 of the 175 total relations found in the classroom data.

The students' use of grammatical metaphor was minimal, and *make* was the only causal process used by the students throughout the ten experiments. Nominalizations were rare as well, although Barbie's effort to describe the difference between *repel* and *not attract* in the interview showed that she seemed to understand the role that nominalization plays in the textual organization of scientific argumentation.

The format Mrs. Montgomery used to teach the unit, with the whole-class discussions prior to and immediately after each experiment, allowed her to focus on honing the students' ability to talk about what they did and what happened, using the appropriate register. While the experiments helped construct field through experience, and while Mrs. Montgomery assisted in this construction by using translation, visuals, and physical action, the students were also being encouraged to "talk science." Answers to the questions which Mrs. Montgomery asked the students made her feel confident that they could understand what they were learning and be able to talk about it outside of the immediate context of the experiments.

The final interviews revealed that some students still preferred to use everyday language, and some had trouble with logical reasoning, but in the discourse of the six students interviewed, there appeared to be a greater use of technicality and a more confident use of language and logical relations than what was exhibited in the final session of Mrs. Sinclair's class. The students seemed reasonably used to talking about magnets in a decontextualized way, using the appropriate science register and providing answers which in most cases revealed a good understanding of the experiments they had carried out.

# CHAPTER 6: MR. PETERSON'S HIGH SCHOOL SCIENCE CLASS

## 6.0 An overview of the chapter

Chapter 4 and Chapter 5 offered a detailed look at how the participants in two primary classes constructed knowledge about magnetism, the teacher's views on this construction, and the causal discourse which the students used to explain their understanding. Chapter 6 examines a mainstream high school science class in which the participants were learning about matter. This chapter examines the classroom interactions and the interview discourse of these mainstream students to respond to the following research questions:

1. How do Mr. Peterson and his students develop causal explanations and their relevant taxonomies through the classroom interactions?
2. What are the causal discourse features which Mr. Peterson's students used to construct oral causal explanations?

As with the chapters about the primary contexts, Chapter 6 will explore Halliday's two types of patterning: the renaming, redefining, and reclassifying of common-sense items to create technical taxonomies, and the reasoned sequences which draw on these taxonomies.

Similar to the previous two chapters, Chapter 6 begins with a look at the events in the science unit, which is Mr. Peterson's chemistry unit on matter. Section 6.2 examines how Mr. Peterson led discussions which explored the concepts he aimed to teach in the unit, including how he attempted to build technicality and link it to the students' background knowledge. This section also describes the language which arose during and after student lab exercises and illustrates Mr. Peterson's efforts to build logical reasoning. The third section of this chapter, Section 6.3, looks at three key concepts of the unit—*physical properties, compounds,* and *mixtures*—and discusses how these were built up through the unit.

Section 6.4 focuses on the extended discourse which nine students offered about what they were learning in this science class, illuminating their ability to shift between congruent, specific language and the more metaphoric discourse about generalized knowledge. The final section offers a summary of the chapter.

## 6.1 Mr. Peterson's chemistry unit

Mr. Peterson's chemistry unit, which was called "Investigating Matter," was the first unit of the school year and lasted approximately twelve weeks. During this time, the teacher not only taught chemistry, but became acquainted with the students and advised them on how to achieve success in his class. Consequently, a fair portion of the discourse revolved around procedures, including learning about the basics of doing labs, such as how to light Bunsen burners and tidy up afterwards.

The students used a school-issued textbook for their science class, *Science Probe 9* (Beckett et al., 1995), published for use in Canadian high schools and recommended by the Province of British Columbia's Ministry of Education. Mr. Peterson said he liked using the textbook because it had local content, lots of teacher support, and a good variety of labs and questions. He frequently assigned readings and questions from the text, and covered most of chapters two, three, and four before moving on to the biology unit in mid-November. Mr. Peterson supplemented this textbook with worksheets he had made, and occasionally had the students use different lab materials from what was listed in the book.

The students did two major labs during the chemistry unit, one in which they observed various chemical reactions, and the other in which they burned a peanut to discover the amount of heat energy it contained. There was also a small lab done cooperatively (between teacher and students) investigating the effects of surface area on the rate of reaction, and several demonstrations aimed at showing chemical reactions, illustrating the Law of Conservation of Mass, showing endothermic and exothermic reactions, and other topics. Table 6.1 outlines the major labs, demonstrations, and dates of the unit.

In the first few days of the unit, Mr. Peterson created his seating plan, which was based on the students' own choices of seats, he distributed the textbooks and handouts concerning the course information, he introduced the researcher (who introduced the study), he had the students create a chemistry title page for their notebooks, and he began with a general overview of the fields of science and the scientific method before starting a discussion about physical properties.

**Table 6.1: Major events in Mr. Peterson's chemistry class**

| Dates* | Task |
|---|---|
| September 17–18, 2001 | Begin Chapter 2 on Changes in Matter |
| September 20–28, 2001 | Lab: Observing Changes in Matter |
| October 1–9, 2001 | Demonstration: Mass of Reactants and Products<br>Demonstration: Mass and Gas |
| October 10–11, 2001 | Begin Chapter 3 on Symbols and Formulas |
| October 15–16, 2001 | Test on Chapter 2 |
| November 2–5, 2001 | Test on Chapter 3 |
| November 7–8, 2001 | Demonstration: Liquid Nitrogen |
| November 6–9, 2001 | Lab: Energy Stored in Food |
| November 13–16, 2001 | Demonstration: Endothermic and Exothermic Reactions |
| November 15–20, 2001 | Lab: Testing Predictions<br>Demonstration: Investigating Catalysts |
| November 27–28, 2001 | Test on Chapter 4 |

*The dates cover all three class groups.

## 6.2 Constructing knowledge in Mr. Peterson's class

In a discussion with Mr. Peterson several months before the data collection in his grade nine science classes began, he stated that his lessons were heavily "teacher-centered," with a lecture-style presentation format and regular student labs. The data show that the lessons were, for the most part, very teacher-controlled. Many of the teacher's questions probed students' background knowledge and experience. These questions helped build technicality through renaming, redefining, and reclassifying the students' common-sense understandings of the topics being explored. The following sections will discuss the construction of knowledge through Mr. Peterson's actions and guidance of the classroom discourse.

### 6.2.1 Building technicality: Renaming, redefining, and reclassifying

Mr. Peterson's frequent use of questions to promote interaction and discussion probed the students' existing understanding of the topics he was introducing. For example, in introducing the textbook's chapter three on writing symbols and formulas, a topic which concerned the Periodic Table of the Elements, Mr. Peterson asked the students about their understanding of elements:

| | |
|---|---|
| Teacher: | Can you tell me... what's an element?... If you had to describe to someone that's asked you what's an element anyway? I don't quite get it. What would you say? |

He had not taught this, although he had named several elements during an earlier discussion of physical properties. Instead, as with many of the questions he asked, he assumed that there were students in the class who would attempt an answer on which he could build further knowledge, and he was not usually disappointed:

| | |
|---|---|
| Dean: | They're substances that can't be broken down into smaller ones. |
| Teacher: | Okay. What else? That's good. Anything else you can say?... What's an element composed of?... Okay go ahead. Yes? Anybody going to help us here? Go ahead. There's an element.... Is the element made up of anything smaller? |
| Evie: | Atoms. |
| Teacher: | How many types of atoms? |
| Student: | One. |

Mr. Peterson continued the topic by asking students basic questions about the atom and its components, eliciting the students' knowledge of a topic not previously introduced in his class, knowledge which he could use as building blocks for his own explanations later.

Mr. Peterson's questions did not focus only on prior science knowledge. He also asked questions about other areas and then made connections between the responses and the topic being discussed, thereby helping students redefine and reclassify their existing knowledge to construct science knowledge. Although this was a method he used often, it was especially noticeable in his talk about physical properties, as the following four examples show. First, rather than stating that hydrogen is flammable, he asked the students if they had heard of the Hindenburg. He followed this with eight related questions, connecting the Hindenburg to the Goodyear Blimp and the element *helium* before continuing to other physical properties.

Second, when discussing boiling points as a property, he asked where water boils at the lowest and highest temperatures, making connections between the physical geography of the world and air pressure, and the relation of air pressure to boiling points. Third, when talking about mercury, he included information from the local news, which had recently reported a death from mercury poisoning, and asked students about the story *Alice in Wonderland,* relating the Mad Hatter of that literature to hat-makers who used mercury in their production process. Finally, Mr Peterson introduced the notion of malleability and softness by eliciting the name of a soft metal from the students and elaborating on the response by asking further questions which demanded background knowledge:

| | |
|---|---|
| Male: | Gold. |
| Teacher: | Uh gold. Yes. Gold. In fact how did the pirates used to tell if a coin was gold or not? |
| Male: | Bite it. |
| Teacher: | If they left their tooth marks in it... there's a chance that it's gold. Right? If it didn't... maybe it was copper. Right?... All right. So gold is another one. It may even be more malleable than lead but it's a similar idea. Um... do you... if you have gold jewelry... rings necklace whatever... is it pure gold? |
| Students: | No. |
| Teacher: | Why not? |
| Male: | It's mixed with copper. |
| Teacher: | It's too expensive? |
| Students: | No. |
| Max: | It's too soft. You can damage it. |
| Teacher: | There you go. It's too soft. So a gold bracelet a pure gold bracelet or necklace just the slightest yank on the chain... would break the links. I mean it's so soft that it's right up there with lead. So they mix gold with other metals to make jewelry. Right? And... the amount of the other the amount of gold is expressed in terms of? |
| Male: | Carats. |
| Teacher: | Carat value. Right. What's carats? |
| Male: | How much gold is in there. |

These questions about pirates, airships, geographical locations, and word definitions allowed students who may have felt that chemistry was not their strongest subject to offer answers from their background knowledge and see how they connect with science.

Aside from asking direct questions about prior science and non-science knowledge, Mr. Peterson attempted to make sense of the topic by using the students' and his own direct experiences. After watching a demonstration of liquid nitrogen, for example, he asked the students about the coldest temperatures they had felt. One boy stated that he had camped in winter in the Northwest Territories in temperatures of fifty degrees below zero Celsius, topping the teacher's tale of his experiences on British Columbia's Whistler Mountain. Mr. Peterson prompted a discussion which involved types of insulation material (e.g., goose down, Polar Guard), the temperature in household freezers, and the coldest weather temperature ever recorded on Earth. These topics were eventually brought together in relation to the boiling point of the liquid nitrogen they had just seen:

Teacher: What you just saw... way colder than that. I mean it makes minus ninety like warm in comparison!

The students were encouraged to offer their experiences of cold not simply to create a discussion, but so that their personal experiences could be compared to the harder-to-imagine cold temperature of the liquid nitrogen, thereby redefining the concept of cold and allowing the students to get some sense of the newly introduced abstract notion of cold, something which they cannot experience.

Although Mr. Peterson drew from students' prior knowledge of a variety of fields, he did not often make direct analogies to common, cultural experiences. His only exception was a comparison of a chemical reaction word equation to double dating. He explained that in the chemical reaction, the chemicals "kind of like they switched partners." His analogy attempted to make the students understand that when a compound consisting of a metal and a nonmetal reacts with another metal and nonmetal compound, the product will continue to be two compounds phrased as metal and nonmetal, in that order. The products would never be two metals and two nonmetals:

Teacher: Are you with me here? Switch partners. Did I give you an analogy about double dating?
Student: Double dating?
Students: No.
Teacher: Oh now you're thinking what's he talking about now? Um.
Student: You're so crazy!

| | |
|---|---|
| Teacher: | Imagine this. Um just about the switching partners thing. Here's my analogy. Two couples are on a double date... right? And they decide that they like the other person's partner better than who they came with... so they decide to switch. But... when they switch it's still boy girl and boy girl. Not boy boy and girl girl. *(Students laugh.)* |

The teacher suggested to the students that if they were going to guess at the products, knowing the reactants, they would make a more educated guess if they could remember that the outcome is "still boy girl." His rare use of analogy therefore gave the students a way to connect the common-sense names *(boy, girl)* with the scientific names they would be learning about.

Mr. Peterson did not depend entirely on the students' non-science prior knowledge throughout the unit. He also asked questions about the homework he had assigned and the labs and demonstrations the students had recently experienced. Moreover, he related his questions and comments to the visible context, such as the colors on the Periodic Table or small, on-the-spot demonstrations he gave, as in the following discussion of the density of various objects in relation to water:

| | |
|---|---|
| Teacher: | Um cork... what do you think? Less than... less than point nine or more? |
| Students: | Less. |
| Teacher: | Here's— here's a rubber stopper in water. *(Drops it in.)* |
| Students: | Whoa! |
| Teacher: | Rubber's more dense than water. Here's a cork in water. *(Drops it in.)* |
| Male: | Less. |
| Male: | Wow. |
| Female: | Cool! |
| Teacher: | It floats quite high right? |
| Students: | Yes. |
| Female: | It's so cool. |
| Teacher: | Okay. Ice would float lower. Right? Cork's around point two five. About a quarter as dense as water... Now... why things sink or float in water is dependent on density. |

This mini-demonstration, along with the information being constructed through the discourse, led to further questions which brought in new information that he could not demonstrate, such as why steel-hulled freighters float. By using this method, Mr. Peterson seemed to be facilitating the construction of more elaborate taxonomies by combining visible, observable phenomena (the equipment he was manipulating) with students' prior knowledge (e.g., asking what they think) and introducing potentially new information, including nominalized terms (e.g., *density).* The relatively high participation rate suggests that he was usually successful in his efforts to involve and interest the students.

Mr. Peterson also connected potentially new terms with materials that he believed the students would be familiar with outside of the science class, as the following excerpt on viscosity and a later example of solubility illustrate. To help define viscosity, the teacher had the students consider such products as oil, honey, molasses, and water, focusing on the contrast between honey and water. To define solubility, flour and sugar were contrasted. By connecting what he assumed most students had experienced with the concept he was attempting to define, Mr. Peterson could help the students visualize the concept, thereby helping them construct knowledge about them.

As Mr. Peterson asked questions and discussed various topics, he introduced and reinforced the language associated with those topics. For example, when discussing physical properties, he asked the students to consider specific differences for which he then offered the term and reinforced it with more questions:

| | |
|---|---|
| Teacher: | Now I'm getting at this other property. Um... this property— a huge difference is would be between say oil and liquid honey. |
| Male: | Oh. |
| Student: | One is thicker. |
| Teacher: | Thickness. Yeah. I guess yeah you know. Honey is very difficult to pour. Molasses. Did you think of that? If you've ever poured molasses?... It's like super thick honey. Right?... Um... so thickness of liquids... is... called... viscosity. Now viscosity is about... thickness of liquid. So it's so it's I think only used... when you talk about liquids. It's like malleability is only used when you're talking about solids. Specifically metals. Okay? So what do you think? Which is more viscous? Honey or water? |
| Students: | Honey. |
| Teacher: | Now more viscous is thicker. You're right. Good. So um... more viscous equals thicker. Right. Now I think it's important you get |

| | |
|---|---|
| | that because... I don't know... that's unless you've caught that you might not be sure. Does more viscous mean thinner or thicker? |
| Student: | Thicker. |
| Teacher: | Thicker.... Okay. Oil is more viscous than water. What happens to the viscosity of honey... when the temperature goes down? |
| Male1: | It gets harder. |
| Female1: | It gets harder? |
| Male1: | It gets less viscous. |
| Female1: | No it gets [more viscous. |
| Teacher: | [The temperature drops what happens to the honey? Or to put it another way you got honey and you heat it up. Put it in the microwave. |
| Female2: | It melts. |
| Male1: | It gets thinner. |
| Teacher: | Less viscous. Right? It's thinner. It's easier to pour if you heat it up. Right? |

Mr. Peterson used the students' suggestions of the more everyday notion of *thicker* and *thinner* to introduce the term *viscosity,* stating that the new term applies specifically to the description of liquids. He used the concept in both a relational clause ("Which is more viscous?" or "viscous equals thicker") and as a nominalization ("viscosity"), matching the nominalization of the new term with the nominalization of the everyday term, and the adjectival form of the science term with the adjectival form of the more familiar term, thus renaming the everyday experience and equating it with science:

| | | |
|---|---|---|
| thickness of liquids<br>value | is called<br>relational process | viscosity<br>token |
| more viscous<br>token | is/equals<br>relational process | thicker<br>value |
| more viscous<br>token | means<br>relational process | thinner or thicker?<br>value |

The questions Mr. Peterson used to check the comprehension of the new term all involved causal discourse, using temporal conjunctions. By shifting from definitions using relational process to these temporal/conditional questions, he was able to check whether the students understood the concept:

What happens to the viscosity of honey when the temperature goes down?
*(When X, what happens to Y?)*

The two quick answers to this question involved the more congruent term, *harder,* which was correct in everyday terms, but not as precise as the newly introduced term because *harder* can apply to more than liquids. The next response suggested that the concept of viscosity may have been confusing to the male student who answered by equating *harder* with *less viscous,* but not confusing to the female student who corrected him. Mr. Peterson rephrased the question as another causal construction and received one response which he did not acknowledge and another which he recast with the target term followed by two everyday equivalents, the latter constructed as another causal conditional. Finally, he wrote the term *viscosity* on the board under *physical properties* and later reminded the students that any of the terms which he wrote on the board were "testable."

Mr. Peterson attempted to bring back these words as their meanings were needed in later discussions. He did this by using the past tense as well as lexical markers such as *again* and *remember* to prompt the students that he had previously introduced the knowledge he was eliciting:

> Teacher: What's the term for thickness **again? Remember** that? Thickness of a liquid. There's a term that applies to that. It **was** one of our physical properties.

The linguistic choices the teacher made helped lead the students to use the technical term which had earlier been taught and thus helped make connections among the ideas he was presenting.

Mr. Peterson not only introduced new terms using relational process and conditional questions, as noted above, he also tried to encourage students to examine the parts of the words to get meaning from them. This strategy was made explicit during his lessons on writing chemical formulas, at the beginning of which he spent a considerable amount of time asking students to think of words which had the same prefixes as what they would be using to describe covalent bonding (e.g., *mono, di, tri).* The teacher's rationale for this was not only to help the students extract meaning, but also to connect the terms to their prior knowledge:

> Teacher: It's important that they feel... I try to facilitate them feeling as comfortable as possible with it *(it = extracting meaning from words).* Um so it's a big emphasis and that's why I would have

| | |
|---|---|
| | spent time with those prefixes looking for examples. Like what are some other situations you've heard mono being used or penta being used or whatever. And hopefully um looking at other examples it's kind of more like to stick in their mind rather than being some obscure prefix that never ever comes up again. And the same with hetero and homo um or... you know virtually any other prefix that I come across. Hyper and hypo. What's hyper mean. |
| Researcher: | Mm-hmm. Exo and endo. |
| Teacher: | Yeah exo and endo. Yeah so I think I put a fair amount of emphasis on it um with examples because I think it's quite important. I really try to stress that if you can break down some of the bigger words into their bits and if you know what the bits mean you can figure out— It's amazing how many words you can figure out. (Interview with teacher) |

The teacher's concern with making connections between the new language of chemistry and the students' prior knowledge was constantly noticeable in the discourse he created.

At times Mr. Peterson needed to correct the students' language by emphasizing the appropriateness of specific word choices and thereby reinforcing the redefinition of common-sense understanding to the scientific. While talking about the findings from a lab which the students were just completing, for example, the teacher asked about the descriptions they had written in their data charts:

| | |
|---|---|
| Teacher: | Okay the one that did react... uh how did you describe what's going on there? Did you say... the magnesium dissolved in the acid? |
| Students: | Yes. |
| Teacher: | Okay. The word— I'm going to help you on a bit of terminology here. Dissolving... is a term that you should reserve for what happens when you put salt or sugar or something like that in water. It disappears... but if you evaporate the water what do you get back? |
| Students: | The salt. |
| Teacher: | The salt or sugar comes back. That's dissolving. Okay? What you saw is a chemical reaction. Okay? You might go it fizzed and disappeared or whatever but don't use dissolving. It's not the right term. How about melting? You put it in the acid and it melted? What's melting? |
| Irene: | It's not melting because it's a phase change. |
| Teacher: | Melting is a phase change from solid to liquid when you reach its melting point. That's not what happened either. So the magnesium ribbon did not dissolve. It did not melt. |

| | |
|---|---|
| Brad: | It turned into smoke. |
| Teacher: | Okay?... It reacted. |

The teacher defined each of the incorrect terms by using features of causal discourse to explain what happens in each scientific process:

| | | | |
|---|---|---|---|
| dissolving | is | **when** you put salt in water and<br>**if** you evaporate it, it comes back | *(temporal)*<br>*(causal conditional)* |
| token | rel:int | value | |
| melting | is | a phase change **from solid to liquid**<br>**when** you reach its melting point | *(circumstance)*<br>*(temporal)* |
| token | rel:int | value | |

He established with the students that neither of these two processes were accurate, and that "it reacted" was the best way to describe what had occurred. On later occasions when the students offered the wrong term, Mr. Peterson would not correct them explicitly, but would flag the problem with technicality by repeating the word with rising intonation (i.e., as a question) as the following two examples show:

Example One:

| | |
|---|---|
| Irene: | And one will be like chopped up and the other will be like melted? |
| Teacher: | Melted? |
| Male: | Wrong! |

Example Two:

| | |
|---|---|
| Tina: | Well you can't because the salt's already melted in the water. |
| Teacher: | Melted? |
| Tina: | Not melted. Dissolved. |

To help teach the concept of *reaction,* Mr. Peterson did several demonstrations in which he put two solutions together (e.g., potassium iodide and lead II nitrate) and discussed the changes which had occurred when the chemicals reacted. Moreover, he showed the students a video (the only video of the unit) which presented elements which he could not order for classroom use. The video illustrated various reactions from mild (e.g., sodium and water) to violent (e.g., cesium and water). The video and the demonstrations offered the students a powerful visual experience to connect to the concept, and the students became very excited when they saw these reactions occur. Some still, however, confused the term with other terms.

The discussion so far has revolved around Mr. Peterson's discursive practices through which science knowledge was being constructed by renaming and redefining everyday experience and creating scientific taxonomies. The students' prior knowledge, or the teacher's presumptions about their prior knowledge, played a major role in this construction. It became obvious through the interactions that many of the students had a good grasp of the appropriate language and grammatical metaphor which allowed them to shift between science and everyday language and between clauses and nominal groups. This was made very apparent by the following example in which the teacher asked which physical property would distinguish icing sugar from white flour:

| | |
|---|---|
| Irene: | Um put it in water? |
| Teacher: | And? |
| Irene: | And one will be like chopped up and the other will be like melted? |
| Teacher: | Melted? |
| Male: | Wrong! |
| Female: | One will be like glue. |
| Teacher: | Melted is a phase change from solid to liquid. |
| Irene: | Well no. It... dissolved. |
| Teacher: | Dissolved. Right. Which one dissolved? |
| Male: | The soluble one. |
| Teacher: | There you go. So the property is? |
| Male: | Solubility. |
| Teacher: | That's good. Right... solubility. Um and... what's the substance called that that... other things dissolve in? What's that term? |
| Male: | Solvent. |
| Teacher: | Solvent. Good... Yeah. Solubility in a solvent.... The substance dissolved? It's got to be soluble. Sugar does. Flour doesn't. Flour just makes a paste right? So it doesn't dissolve no matter how much you stir it... or heat it... it doesn't dissolve. |

In the above excerpt, Irene shifts from everyday language, which others quickly pointed out was wrong, to the more appropriate term *dissolve*. From this, three related terms arose: *soluble, solubility,* and *solvent*. At least one student appeared to be familiar with this taxonomy, and when questioned, was able to respond using the correct word. The teacher reinforced this mini-taxonomy for the rest.

Vocabulary did not seem to be an issue for the students who were regularly participating in these oral interactions. Nominalizations which suggested word taxonomies such as the one above appeared in the appropriate responses, and although the students' answers were typically short, as previously mentioned, they reflected a good amount of prior knowledge in science, in other academic fields, and in everyday understandings, knowledge which the teacher valued, relied on, and on which he attempted to build further science knowledge.

### 6.2.2 Prompting logical reasoning

Mr. Peterson at times created scenarios and asked students to respond to these using their prior knowledge and problem-solving abilities. These scenarios created opportunities for the students to think about their own experiences and understandings and to apply these to the topic at hand. This form of questioning prompted logical reasoning and involved the use of causal discourse:

| | |
|---|---|
| Teacher: | So what we're going to do is try to derive a list and there could be at least ten or more different types of physical properties. So these are ways you can distinguish between substances. Okay? So for example. Start you off really easy here. I've got... two containers here... this one... and this one... Okay? So what do you think? Do you think these are the same substances in these containers... |
| Students | No. |
| Teacher | or different. |
| Students | Different. |
| Teacher | How do you know? |
| Student | Because they're different colors. |
| Students | Color. |
| Teacher | There you go. So color's probably the most obvious first physical property that helps you tell. |

He continues a few words later:

| | |
|---|---|
| Teacher: | Say um... say I had a glass of water... nice filtered cool water and in the other hand I've got a glass of... cool alcohol. Rubbing alcohol. Which is poison... Okay? And you are desperately thirsty. You've just come in off the field and you you're you know you want a drink of water. It'd be great. So I go being kind of a mean guy I go hey I've got this drink for you. I got some water here well I've got water and I've got alcohol and I'm not telling you which one is which... How would you tell the difference? |
| Students: | Smell. |

Teacher: There you go. There's another physical property. See water and alcohol you can't tell the difference between them by looking at them. But… smell will do it.

In the first part of the example above, Mr. Peterson built a causal relation by suggesting that color is the property which causes people to determine the difference between substances. In the second part, the causal relation of *if… then…* is implicit, but the students appear to know that Mr. Peterson is asking *if these two liquids look the same, how do you tell them apart?* They therefore offer *smell* as a response. The teacher then continues, making the problem more difficult to solve:

Teacher: Okay how about this. Same scenario. Alcohol and water. You definitely want a drink and you want a drink of water and unfortunately you've got a cold. So… your smeller doesn't work.
Student 1: Your smeller!
Teacher: In fact you can't smell the difference and they look the same… now so you have a problem. How would you deal with that?
Student 2: Well taste.
Student 3: Touch it.
Student 4: Pour it in a cut.
Teacher: If you had a cut you pour it in the cut then what?
Student 4: It stung!
Teacher: The alcohol stings. Okay. *(Some students laugh.)* That's all right. Fair enough. Unfortunately or fortunately you don't have a cut. So… you heard me not say that's wrong. I mean I appreciate that. That's good. It probably works. It might depend on your pain threshold. Some of you might not notice it. Okay.
Student 3: It'll dry out pretty fast.
Teacher: Sorry?
Student 3: If you pour it on your skin it'll dry out pretty fast.
Teacher: Ah okay. So you put… you could put um some alcohol on one arm say and water on the other one and…
Student 3: The one that evaporates quickly
Teacher: The one that evaporates fastest
Student 3: is the alcohol.
Teacher: is the alcohol. Would you agree?

Mr. Peterson used the same implicit style of causation as his earlier scenario above, but when Student 4 offers a solution to the problem, the teacher responds with an *if… then…* relation to probe the response. Student 4 responds with a specific event ("it stung"), which Mr. Peterson generalizes ("it stings"). When Student 3 offers a response, it is repeated using the same causal *if... then...* relation in the timeless present.

Student 4's past tense answer about a specific event captures that student's background experience regarding alcohol and cuts in response to Mr. Peterson's past tense question of "if you **had** a cut you pour it in the cut then what?" In fact, Mr. Peterson often used the past or perfect tense to elicit the students' experientially based prior knowledge:

| | |
|---|---|
| Teacher: | If you**'ve ever poured** molasses?... It's like super thick honey. Right? |
| Teacher: | When you **added** the water to those crystals and it kind of **went** blue? |

Questions which elicited general knowledge did not use these forms and instead were constructed in the timeless present.

In the above example, Student 4's experience-based answer made several of the other students laugh. Mr. Peterson did two things in response. First, he recast the student's answer, which had been initially cast in the past, by using the timeless present to show that the student's experience reflects the general result of putting alcohol on cuts. Second, he encouraged the student by stating that the answer was a good answer even if it was not the one he anticipated. This type of encouragement for oral participation was a regular part of his interactions, and he took the time to remind students that part of their course mark would be based on oral participation, which included making an effort to answer and even putting their hands up during class polls. Mr. Peterson even appeared to accept wrong answers, although when they occurred, he noted that they were wrong in a friendly way:

| | |
|---|---|
| Teacher: | If you're boiling water... there's bubbles coming up from the bottom. Big bubbles... what's in the bubbles? |
| Students: | Air. |
| Students: | Gas. |
| Teacher: | Yes. Gas. That's a pretty safe answer. What gas? |
| Student: | Carbon dioxide? |
| Student: | Oxygen? |
| Teacher: | Okay. Oxygen's one... uh answer. Okay? It's not the right answer though. *(Students laugh.)* Ah another one? |

This acceptance of all answers seemed to encourage students to call out answers based on their own experiences and understanding.

Using humor to make the students laugh was another strategy that Mr. Peterson used to promote students' thinking about prior experiences to relate them to the topic under investigation. In the following example, he jokes with the students to get them to consider the concept of evaporation:

| | |
|---|---|
| Teacher | Now who's noticed that— and guys... you might not want to put your hand up here. You know what I'm saying? *(Laughter.)* What does that mean? Ladies? Maybe? Or maybe you've seen your sister or mother or whatever. But have you noticed that nail polish remover evaporates very quickly? Does it feel cool when you get it on your finger? |
| Student | It dries out my skin. |
| Teacher | It dries out your skin. Yeah. That would. So some substances evaporate faster than others. And that is related to another physical property actually. |

He used a *when... then...* construction to show a sequence which implies causality (does the nail polish cause your finger to become cool?), which was answered with a causal action, "it dries out my skin," meaning that the nail polish causes the student's skin to become dry. The causal relations here are then related to another physical property, that of boiling points.

The language that the students used as they did their labs differed considerably from that which they used during whole-class interactions in that it was primarily observational or procedural. In other words, during the labs, the students either commented on what they saw or discussed how to proceed:

| | |
|---|---|
| Andy: | Okay. Check it out. Now what does it say to do? What does it say to do now? |
| John: | Uh let it cool and (xx)... It looks kind of neat. It says let it cool and examine again. |
| Andy: | First we have to put the properties of the (xx). It is uh kind of silver or smoke. *(A test tube falls.)* |
| John: | It didn't break. Okay I'll just let that sit on the table. |
| Andy: | What color is this kind? Bronzish? Copperish? |
| John: | Yeah it's a coppery color. Coppery. |
| Andy: | Well like what color? |
| John: | ... Gold. |

Andy: Goldish? No way!

John: A brownish color. Brownish color. Uh...

Andy: Um let's see. Oh yeah yeah. It's very flexible.

Although this was the normal style of discourse during hands-on lab work, there were also examples of the students offering spontaneous explanations for their findings. These typically occurred as they were reflecting on what to write in their observation data charts:

Brad: *(Talking about the copper wire which had turned color.)* It turns pink. Do you know why? Because there's supposed to be a new piece of wire. We had an old one so it then it got really rusty. I thought we could put it down. It had green stuff. That's what I'm putting anyway.

Student: But that was so (xx) anyways. *(They write their responses in their books, and Brad comments on the word* chemical *which he sees the other student has written in the last space.)*

Brad: But this might be physical right? Because you have to evaporate the water to get the crystals back.

Most of the lab discourse remained centered either on the task of *doing* the experiment or on *reflecting* on the outcomes.

Once the students had manipulated the lab equipment and noted some of their results in their data tables, Mr. Peterson called the class to attention and asked the students about what they had done and found, and directed them to the findings they should have had. He did this by questioning the students and by listening or watching for responses:

Teacher: Okay ladies and gentlemen? Pay attention for a moment please.... Okay? How many of you have added the water... to the... test tube for procedure nine? How many have done that? Have you all have... okay. Um... so you notice that— you notice something happened in eight when you heated it. Right? You might have noticed two things that you can report. Okay? Um then when you added the water... something else happened... Did it change color at all when you added the water?

Students: No.

Student: I don't think it did.

Student: It went to blue.

Student: It changed back to its original color.

Teacher: Okay. Like it did when you heated it it did one thing and then when you added the water it might have gone backwards color-wise.

Students: Yeah.

Teacher: Is that fair? Okay. Now... those of you... who held it in your fingers when you added the water... how many of you noticed that it cooled down when you added the water?... Okay? I see a hand or two. How many noticed that it heated up when you added the water?... When you added a few drops of water did anybody notice that it got warmer?

Student: Yeah.

Teacher: Okay hands up if you did... Okay I see two groups. I've noticed that it's got warmer.

After talking about what the students may have noticed (specific reflection), Mr. Peterson then directed the students to go back to their hands-on work. Later, he called the students to attention again to discuss some general theory relevant to the lab and which the students were to use in their lab reports; in fact, determining whether the changes were physical or chemical was a key goal of the lab:

Teacher: Um ladies and gentlemen you know how you're supposed to indicate chemical or physical... right? Now you know that there's a few clues... to whether it's chemical or not. If there's a color change... what?

Student: Chemical.

Student: Oh chemical.

Student: It's all chemical.

Teacher: Chemical uh physical... a color change is one of the clues to indicate what?

Irene: Chemical.

Teacher: Chemical. Right... What if heat's released?

Student: ... Chemical.

Teacher: Chemical. Right. Gas produced?

Student: Chemical.

Teacher: Chemical again. Right. If by the way... you know after you finished say you added the water?... If you evaporated that water. If you heated it up and evaporated all the water? What do you think you'd get?

Student: Crystals.

Student: The crystals back.

Teacher: Yeah you'd get the blue crystals again. What would that be?

Student: Physical.

Student: Physical.

Teacher: Yes. That's just evaporating the water. Okay?

Here, the teacher shifted his language from talking about what happened ("it went to blue," "it got warmer") to causal language using *if*. By doing this, he moved from the specific context of the here and now to the theoretical context of what indicates physical and chemical changes. He did this through a variety of linguistic means, as Table 6.2 shows.

**Table 6.2: Shifts in the discourse from specific to general**

| **Specific** | **General** |
|---|---|
| Processes: | Processes: |
| high number of material processes<br>e.g., *add, do*<br>*heat, change* | more relational and existential<br>e.g., *there is*<br>*is* |
| mental or behavioral processes<br>e.g., *think*<br>*notice* | processes of evidence<br>e.g., *indicate* |
| processes in past tense<br>e.g., *added*<br>*done*<br>*happened* | processes in present tense<br>e.g., *is* |
| active voice | passive voice |
| Conjunctions: | Conjunctions: |
| temporal<br>e.g., *when* | causal<br>e.g., *if* |
| Participants: | Participants: |
| specific participants<br>e.g., *the water*<br>*its original color* | general participants<br>e.g., *a color change*<br>*heat* |
| frequent use of human participants<br>e.g., *you, I* | less use of human participants |

As shown in the examples presented in sections 6.2.1 and 6.2.2, the students' responses during the teacher-led interactions were often short, requiring single-word answers, such as the names of the elements, *yes*, or *no*. At times he phrased the question as a short-answer sentence completion. Occasionally, he asked questions like "how do you know?" which were answered in short sentences:

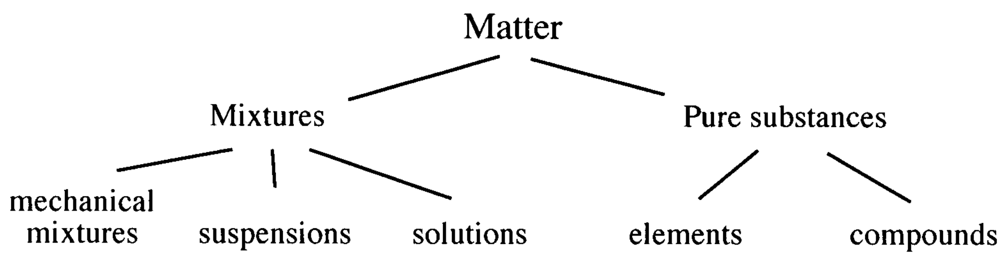
Teacher: Oil's less dense than water right?
Female: Yeah.
Teacher: How do you know that?
Male: Oil floats to the top.
Teacher: Oil floats in water. There you go.

Few of the students' utterances in these classroom interactions went beyond a dozen words, yet their contributions played a large role in constructing the science discourse. Stretches of text which did not have teacher questioning and student input did not relate directly to the science content; instead, the teacher's monologues usually constructed procedural knowledge of how to succeed in his science class or how to carry out a lab.

### 6.3 Tracking the construction of three key concepts

Section 6.2 described how Mr. Peterson attempted to build technicality and promote logical reasoning in his chemistry unit. Both Mr. Peterson and the textbook stressed the importance of matter in the study of chemistry—the section of the textbook was called "Investigating Matter." The taxonomy of matter which the textbook presented and which Mr. Peterson followed in his teaching of mixtures and compounds classified matter into mixtures and pure substances, as Figure 6.1 shows. The next sections will focus on three key concepts—*physical properties, compounds,* and *mixtures*—and examine how these were developed through the interactions and activities Mr. Peterson directed. The topic of physical properties was taught first, and compounds and mixtures were related to the properties whenever possible.

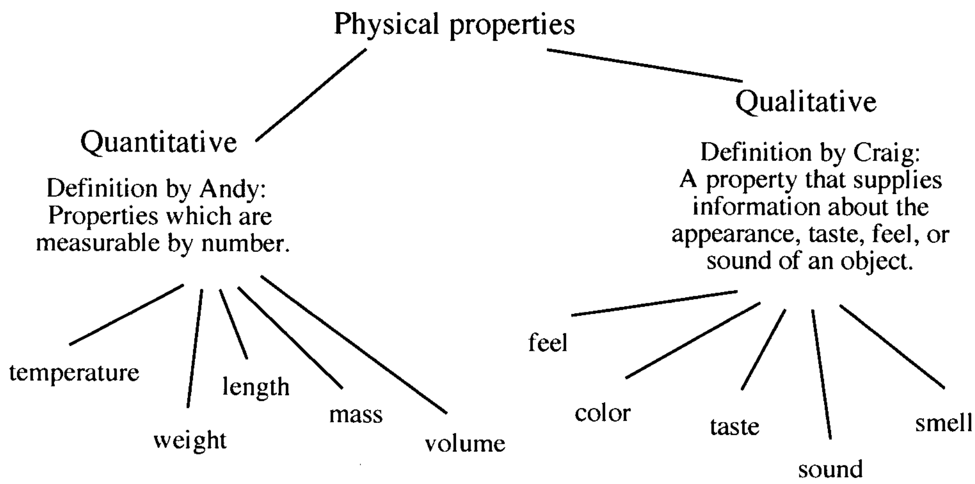
**Figure 6.1: The taxonomy of matter presented in Mr. Peterson's class**




#### 6.3.1 Building up an understanding of *physical properties*

The topic of physical properties was introduced at the beginning of the chemistry unit, and prior to starting a discussion, Mr. Peterson assigned homework which required the students to read about scientific inquiry and to define qualitative and quantitative properties, supplying examples of each. In class, he reviewed these questions by asking students for the definitions they had constructed and by asking several students for their examples of each. The initial taxonomy which resulted from the students' suggestions is captured in Figure 6.2. This taxonomy was never drawn visually for the students; instead, Mr. Peterson spent the rest of that class session plus the next working with the students to create a more detailed list of physical properties, thereby adjusting this initial taxonomy.

**Figure 6.2: The initial taxonomy of physical properties**




The list which Mr. Peterson constructed with the students did not explicitly divide the properties into qualitative and quantitative properties, as Figure 6.2 suggested, so in that respect, the jointly constructed taxonomy could be considered less deep, with physical properties at the top and the twelve properties discussed immediately under the title. Yet although Mr. Peterson did not explicitly state which properties were quantitative and which were qualitative, he gave some indication through the examples he discussed. For example, common boiling points and freezing points were stated and put on the board as examples, and density was accompanied by the formula by which it is calculated: grams per cubic centimeter. Mr. Peterson also listed the density of various elements (see Figure 6.4).

Density as a property offered an interesting case of contrast between the taxonomy in Figure 6.2, which had been created by the students initially, and the concepts which Mr. Peterson was trying to teach. Whereas the quantitative properties initially presented highlighted *weight, mass,* and *volume,* the teacher aimed to expand on and connect these to construct the concept of density as a physical property:

Teacher: What's the difference between lead and aluminum?
Irene: Lead is heavier.
Teacher: Lead is heavier. There you go. Now… if somebody says that, I go… oh yeah? I go in the back and I rummage around to find a huge piece of aluminum. A big chunk of aluminum and a tiny lead thing… and I'll bring them out and I'll go okay… lift them. I can make the aluminum so big and the lead so small that the aluminum is actually heavier. Couldn't I? Think about it.
Irene: You have to compare equal volumes.
Teacher: Oh, I'd have to compare equal volumes to be fair. In other words we're comparing… density. So if you're asked what's one of the differences between lead and aluminum don't go weight… because a guy like me is going to prove you wrong. Okay? It's density. Right? Is everybody clear on that?
Students: Yeah.
Teacher: Okay so you're comparing equal size amounts.

This example suggests that the taxonomy which Mr. Peterson was attempting to create through the discussion with the students was somewhat different than the one the homework assignment had prompted, and visually more complex in that connections would need to be made amongst *weight, mass,* and *volume.* Figure 6.3 attempts to capture this complexity.

**Figure 6.3: Building on the initial taxonomy**

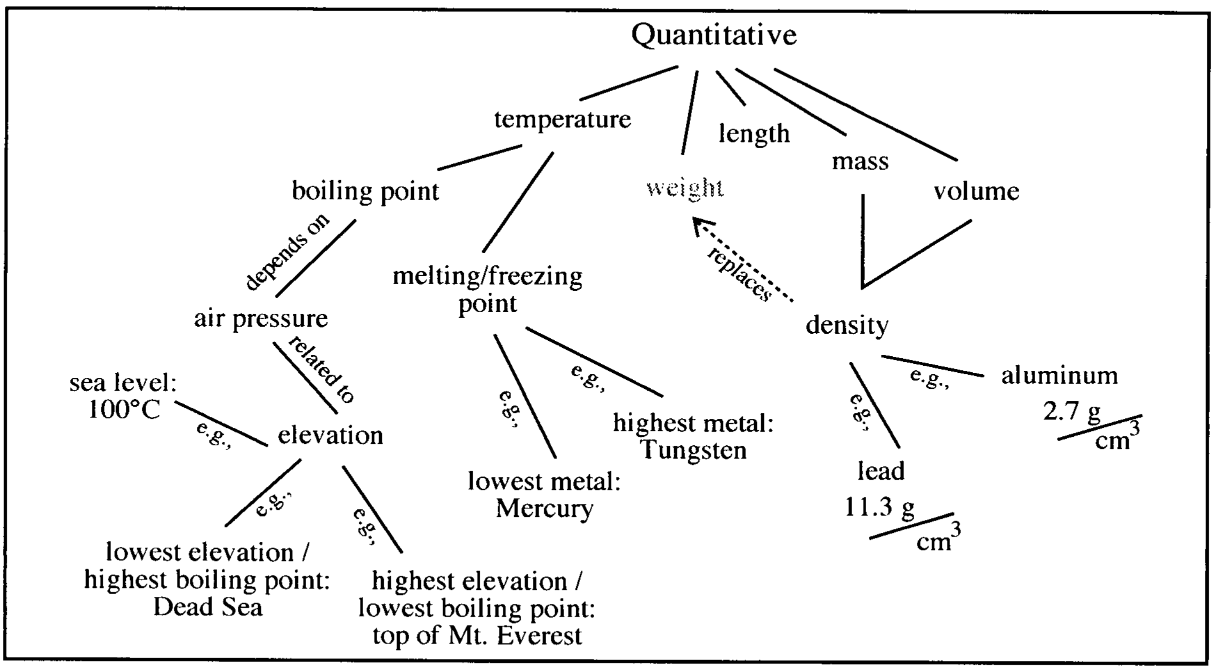


Figure 6.3 also shows how the discussion added to the basic concept of temperature by introducing both the concepts of boiling points and melting or freezing points. Moreover, Mr. Peterson's probing created a further connection between boiling point and air pressure:

| | |
|---|---|
| Teacher: | What does boiling point depend on?... How about this? Say you went up a mountain... |
| Student: | Air. |
| Teacher: | Any mountain. Higher than sea level. What do you think happens to the boiling point of water? Does it change? If so does it go up or down? |
| Students: | Go down. |
| Teacher: | You're right. If you go up a mountain... think about it. What happens to the air pressure? |
| Student: | Go up. |
| Teacher: | Does it go up? |
| Student: | It's less. |
| Teacher: | Less air pressure. Particles in the air are further apart. Is that fair?... So each breath you take as you go up a mountain is less air going into your lungs. Is that fair? |
| Student: | Yeah. |
| Teacher: | Does that explain why mountain climbers find it more difficult to breathe the higher up they go? |
| Students: | Yeah. |
| Teacher: | With each breath there's less oxygen. Think about it like this. Um as you go up a mountain... say you're trying to boil water. There's less air pushing down on the surface of the water you're trying to boil. There's less particles now there's more spaces for the water molecules to go into if you boil the water... so the water boils at... a lower temperature as you go higher. Right? Water's boiling point is one hundred only at... what level? |
| Students: | Sea level. |
| Teacher: | Right. |

Mr. Peterson then went on to elicit the places on Earth where the water boils at the highest and lowest temperatures. The taxonomy he was building became more and more complex because of the connections he was making, as Figure 6.3 attempts to capture.

By the end of the two-day construction of the list of physical properties, Mr. Peterson had defined the overall concept and had written twelve properties on the white board, each with examples and/or definitions, and all students had copied this information into their notebooks. This list is captured in Figure 6.4. The list adds a great deal to the initial task of defining and giving examples of qualitative and quantitative properties. The discussion which Mr. Peterson led not only added more properties to the taxonomy, it helped to make more connections between these and the initially proposed properties as well as introduced other science (and non-science) concepts which play a role in defining and understanding the various items in the taxonomy.

**Figure 6.4: Mr. Peterson's list of physical properties**

Physical Properties

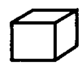
characteristics that can be used to distinguish amongst substances

color

smell

boiling point — is dependent on the air pressure/distance above or below sea level
(BP)
- as you go up a mountain, the BP decreases
- BP of water is 100°C only at sea level

freezing/melting point
- lowest MP metal: Mercury
- highest MP metal: Tungsten

density: mass per unit volume e.g., $\text{grams}/\text{cm}^3$ 

gold 19.3 $g/cm^3$
lead 11.3 $g/cm^3$
aluminum 2.7 $g/cm^3$
iron 7.8 $g/cm^3$
copper 8.5 $g/cm^3$
mercury 11.5 $g/cm^3$
osmium 22.6 $g/cm^3$ (most)

water 1 $g/cm^3$
ice ~.9
cork ~.25

malleability — softness; how easy it is to hammer flat

magnetism — 3 metals are attracted: iron, nickel, cobalt

conductivity (heat or electricity) — best: copper, silver, gold

solubility — does substance dissolve in water?

viscosity — thickness of liquids. More viscous = thicker

ductility — how easily metal can be made into wire

crystal shape — e.g., table salt is cubic

So far this section has discussed what Mr. Peterson presented; in other words, it has looked at the field he was attempted to build. The section has not said much about how the teacher tried to construct this field with the students. Section 6.2 described the questioning which Mr. Peterson did to probe the students' science and relevant non-science background knowledge as well as how he helped students build technicality. These interactions—direct questioning, describing scenarios for which students needed to solve a problem, and bringing in information from other subject areas such as literature (Alice in Wonderland), and geography (Mt. Everest and the Dead Sea)—helped connect the students' background knowledge with the new concepts. Whenever possible, Mr. Peterson also did small demonstrations to support the ideas he was presenting. He showed the students various solutions when discussing solubility and dropped both a rubber stopper and a cork into a beaker of water to help illustrate the concept of density. When discussing malleability, he showed the students how easy or difficult it was to bend steel, zinc, copper, and lead, demonstrating that lead was by far the most malleable of the four:

Teacher: Here's a piece of lead. Okay? Watch this. *(He flicks the metal down quickly and it bends around, hitting his knuckles.)* Oh! It actually wrapped around and hit me. Okay? *(Some laughter.)* Look how bendable that is. I'll try again and just go... *(Does it again.)* But I hardly move it... So very malleable.

Even the concepts of freezing points and boiling points were addressed through a demonstration of liquid nitrogen, as mentioned in Section 6.2. These demonstrations were carried out so that students could connect experience to the concepts that were being introduced. These experiences combined with definitions and examples to help give meaning to the taxonomy which Mr. Peterson was attempting to build.

Mr. Peterson also made many attempts to connect the physical properties to the everyday world of the students by offering and eliciting examples which they would understand and connect to the particular property they were discussing. For example, when talking about solubility, the teacher contrasted icing sugar and flour. When describing viscosity, he asked about honey and water after establishing that more students were familiar with honey than with molasses. After showing the students that lead was very malleable, he asked what the students knew about lead and led a discussion of toxicity, lead paint, leaded gasoline, and old-style pencils. Mr. Peterson also described how pirates used to verify gold by biting it—being malleable, gold would leave tooth marks. Even the measurement of cubic centimeters was related to Honda motorcycle engines in an effort to connect the students' everyday experiences to the physical properties being taught.

After having the students read about the concepts and answer questions in their textbooks, participate in a class discussion which connected their background knowledge to the field being taught, and watch small demonstrations which helped to illustrate the content, Mr. Peterson asked the students to carry out a lab which required them to record the observable physical properties of various materials before and after physical or chemical changes had occurred. The lab, entitled *Observing Changes in Matter,* asked students to describe each substance they were using. Although the descriptions were qualitative, the lab aimed at giving the students practice in choosing appropriate properties to focus on for their descriptions. Later, Mr. Peterson assigned for homework questions from the textbook which required the students to list the properties of various metals. Moreover, when he discussed mixtures, he drew the students' attention again to the list of physical properties, thereby reinforcing the idea that an understanding of these properties is important basic knowledge in chemistry.

### 6.3.2 Building up an understanding of *compounds*

The textbook Mr. Peterson opted to use for his science nine class offered a very clear taxonomy of matter within the same few pages as the concept of physical properties was introduced and defined, at the beginning of the textbook's second chapter. Matter was classified as a mixture or a pure substance, and compounds were listed under pure substances, along with elements. One example of each was given in the visual taxonomy as well as on the facing page. Mr. Peterson assigned these pages as reading homework early on, then assigned some of the review questions for homework about ten days after he had created the list of physical properties with the students. The first question of these required the students to give two examples of an element and two of a compound. After checking that all students had done their homework (a task he did regularly), he involved the students in a discussion about this question:

| | |
|---|---|
| Teacher: | Can you think of an example of a compound?... Now... suggestion if you can't think of one. We used a few compounds in that lab you just handed in. |
| Female: | Copper sulfate. |
| Teacher: | Copper sulfate. There's one. |

He continued eliciting the names of compounds, stating that "there's thousands, there's millions of examples." He also asked the students more about compounds, information which had been introduced earlier in the textbook:

| | |
|---|---|
| Teacher: | What about a compound? How many types of atoms? |
| Students: | Two. |
| Teacher: | Only two? |
| Students: | Two or more. |
| Teacher: | Could it be two? |
| Students: | Yes. |
| Teacher: | Could it be more than two? |
| Students: | Yes. |
| Teacher: | I just thought I'd see if I could catch you there. Okay. So a compound is composed of... how many elements? |
| Students: | Two or more. |
| Teacher: | There you go. Two or more. At least two. Right. And therefore you got at least two different types of atoms. Um... can compounds be broken down? |
| Students: | Yes. |
| Teacher: | By chemical reaction. You can't just separate them... like with a mixture, right? So a compound is at least two different types of atoms that are chemically joined together. There you go. |

His questioning reviewed the reading material he had earlier assigned for homework by using the following steps:

1. Elicits an example from the students current knowledge. *(X is a kind of Y.)*
2. Asks what the components are. *(X is made up of Y.)*
3. Suggests how the compounds can be broken down. *(X is a means to Y.)*
4. Offers a definition of the term by combining information from steps 2 and 3.

Whereas steps one and two are building up taxonomic relationships, step three offers a process, a chemical reaction breaking down a compound, and therefore involves logical reasoning.

Approximately one week after the above conversation occurred, Mr. Peterson brought up the topic of compounds again as he began the third chapter of the text, a chapter which introduced the students to ionic and covalent bonding. He reviewed the concept of elements and reinforced the idea that elements are made up of the same type of atom. He contrasted this to compounds, thereby reviewing the previously introduced information:

| | |
|---|---|
| Teacher: | Those are atoms and they're all the same in one element. If you combine elements together to make... another substance where they're chemically joined together... what do you call that? |
| Student: | Compound? |
| Teacher: | That's a compound. That's right. So combination of at least two different elements... a compound. Okay? |

He then introduced some new information about compounds, once again using elements to offer a contrast:

| | |
|---|---|
| Teacher: | How about this? What's the smallest bit of an element that's like every other bit of the same element? |
| Student 1: | An atom. |
| Teacher: | It's an atom. That's right. What's the smallest bit of a compound that's like every other bit of the same compound? |
| Student 1: | An atom? |
| Teacher: | No. |
| Student 2: | Molecule? |
| Teacher: | Molecule. That's right. |

Although Student 2 correctly answered the teacher's question, further probing by Mr. Peterson convinced him that the students in general were not sure of the concept of molecule, so he continued trying to explain, and at the same time drew Figure 6.5 on the overhead projector:

| | |
|---|---|
| Teacher: | So... this is an element... this is a sample of the element. Say it's a piece of gold. And if you could see them say if you had the most incredibly powerful microscope and see the individual bits that are still the bits of gold... like say you ground up gold into gold dust... and you ground up the dust into such fine particles that you'd need this super microscope to even see them... what's the smallest particles that would still be gold? |
| Student: | Atom. |
| Teacher: | Is gold... atoms. Okay? Now on the other hand let's say we had a compound... like... water. Okay? Water is made of... oxygen atoms and? |

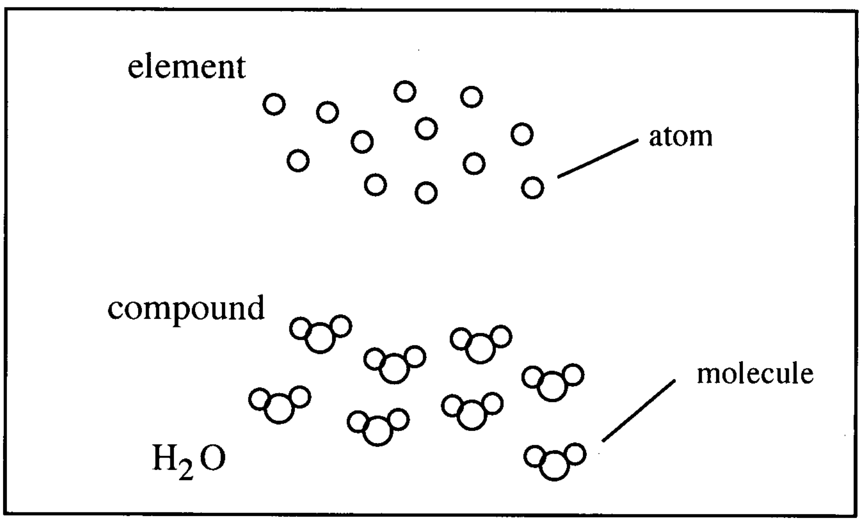
| | |
|---|---|
| Students: | Hydrogen. |
| Teacher: | Hydrogen atoms. H two O. You've probably seen it drawn like a Mickey Mouse head okay? So what's uh and here's a sample of water... *(Draws.)* Got lots of these. If you freeze water they get they... kind of get close together. If you vaporize water make it into like steam? Water vapor? They get further apart. But they're all still these things. Okay? So this is water. The whole... you know a whole bunch of them would be water. What's the smallest bit of water? |
| Students: | A molecule. |
| Teacher: | There you go. |
| Student 1: | So a molecule is two different atoms together? |
| Teacher: | Yes. Now— |
| Student 2: | Two or more. |

He finished the discussion by offering the students a way to think of these interlocking concepts of atoms, elements, molecules, and compounds:

| | |
|---|---|
| Teacher: | So how about this. Does this kind of phrase make sense to you? An atom is to an element... as a molecule is to a compound. Get it? |

This comparison, combined with the visual image he had drawn and the earlier discussion, helped the students understand the nature of the two types of pure substances listed in the taxonomy outlined in the textbook.

**Figure 6.5: Visually defining *compound***




The concept of compounds was further reinforced by the extensive work Mr. Peterson's students did on writing chemical formulas for compounds which were produced through ionic and covalent bonding. The teacher spent approximately one month teaching the students about bonding and how to determine formulas for the products.

What was very noticeable when examining the discourse data surrounding the concept of compounds was that it was not translated into everyday terms. Instead, Mr. Peterson elicited examples and contrasted the concept with the other pure substances in chemistry, elements. Both elements and compounds appear in the textbook's taxonomy of matter, but elements seemed to be the easier concept for Mr. Peterson to introduce. Not only did the students appear to have some background knowledge about elements, Mr. Peterson had the Periodic Table of the Elements posted on the wall to refer to. Moreover, he had used this table when discussing many of the physical properties earlier, so the elements were not new to the students.

To be able to describe compounds more fully, Mr. Peterson needed to introduce the concept of molecules. For this, he used interlocking terms, ensuring that the students understood the terms that he was using. Although *atom* was not defined (but used frequently) in the textbook, the teacher drew a diagram and elicited the parts from the students who were familiar with them, and reinforced the idea that elements were made up of one type of atom. Once he felt confident that the students understood the concept of elements, he used it to build the concept of compounds, which included an understanding of molecules. The four terms interlocked in the relations Mr. Peterson constructed over the course of his questioning:

| | | |
|---|---|---|
| An element | has | atoms. |
| carrier | rel:poss | attribute |
| A compound | has | molecules. |
| carrier | rel:poss | attribute |
| Molecules | have | at least two kinds of atoms. |
| carrier | rel:poss | attribute |
| Compounds | have | at least two kinds of elements. |
| carrier | rel:poss | attribute |

His teaching of bonding helped to illustrate these relations as students learned how to combine two or more elements to make a compound, or two or more atoms to make a molecule.

In sum, Mr. Peterson used the textbook's explanations, visuals, and questions as an introductory foundation to the concepts, then reinforced and built on the concept by presenting his own visuals, asking questions which probed students' background knowledge (eliciting examples and components), and making connections to other activities and discussions already carried out in class. He also connected and contrasted the term with the concept of elements, which he had brought up earlier in the discussion of physical properties and for which he could refer to the Periodic Table of the Elements, a large poster at the side of the classroom. The students seemed to be more familiar with the concepts of atoms and elements, so the teacher was able to use these to help them understand the concept of compounds.

### 6.3.3 Building up an understanding of *mixtures*

As mentioned in Section 6.3.2, the textbook offered a diagram which classified matter into pure substances and mixtures. The homework question which required the students to give examples of elements and compounds also asked for examples of mechanical mixtures and solutions. The discussion which Mr. Peterson led to elicit examples of elements and compounds continued with an elicitation of solutions followed by one of mechanical mixtures.

When Mr. Peterson asked for an example of a solution, he was offered as answers *drink mix* and *sea water.* He accepted those examples, then defined a solution as a transparent fluid and brought out examples to show the students:

Teacher: Solutions... typically you can see right through them. I'll just show you a couple of examples here. *(He goes to his office and comes back with three bottles containing three different solutions.)* Okay... The bottles aren't... very clean on the outside. They've got some dust on them... that's um... potassium iodide solution. Uh it just got shaken up a little bit when I was bringing it out so there's a bunch of little specks in there now, but in fact they settle out. It would be a clear solution. I know it could look like other things but *(Students laugh.)* that's fine. Um... this is called sodium sulfate... solution. It's also got a little bit of stuff floating around now because it got shaken up a little bit. Um... this is copper...

chloride solution... uh which would look very similar to the copper sulfate you know when you added the water to those crystals and it kind of went blue?

What he produced are all examples of chemical solutions which were unfamiliar to the students, but by showing them, Mr. Peterson linked his definition to experience and reinforced the idea that solutions are transparent. Moreover, he connected the last solution he showed to the recent lab experiment that the students had completed.

The teacher then returned to the suggestion of sea water, changing it to salt water. Once again, he attempted to ensure that the students understood that a solution is clear. To do this, he asked them about the difference between fresh and salt water:

| | |
|---|---|
| Teacher: | So... salt water... by looking at it can you tell salt water from fresh water by looking at it? |
| Students: | No. |
| Teacher: | Can you? |
| Students: | No. |
| Teacher: | No you can't. Pure salt water. Filtered salt water versus pure fresh water? No you can't tell by looking at it... Um in case you're thinking well salt water it's kind of... got stuff floating in it like down at the beach say bits of seaweed... you know marine organisms and that... um... so you can tell. Yeah but when it's filtered... can you by looking into the water in a nicely kept aquarium... tell the difference between a salt water and a fresh water aquarium? |
| Students: | No. |
| Teacher: | Just by the water itself? |
| Students: | No. |
| Teacher: | No. No. You can't. So therefore the salt particles when it dissolves must break into... things as small as the water molecules. I mean they're really small. Right? Same with sugar. When you dissolve sugar... the particles are so small you can't see them... even with a microscope. They're molecules. Right? Therefore it's clear. So solutions are clear. Some of them are colored... but they're not cloudy. Okay? |

Whereas Mr. Peterson's initial examples were unfamiliar solutions which the students could experience only as he showed them, the salt water examples above allowed the students to connect the term to their own background experience. This was followed by a sugar-water example which may also have been familiar to many students.

Not only did Mr. Peterson define and provide examples for *solution,* he used the process *dissolve,* a key technical in that taxonomy, which further helped define *solution.* As shown in the previous discourse example, he explained that when particles dissolve, they break down into molecules, and because water molecules and salt—or sugar—molecules are so small, the solution is clear. His parallel of technical language and everyday language is diagrammed in Figure 6.6.

**Figure 6.6: The parallel "translation" of terms in defining *solution***

| | | salt / sugar | |
|---|---|---|---|
| *process* | dissolves | = | breaks into |
| *result of process* | molecules | = | really small particles |

Through Mr. Peterson's explanation, he built technicality by offering an everyday equivalent of *dissolve* and of *molecules,* thereby presenting a translation to help the students understand that when these "things as small as the water molecules" which can't be seen "even with a microscope" are mixed together, the type of mixture they create—a solution—is clear rather than cloudy because the particles are so small.

Mr. Peterson continued his discussion of mixtures by asking for examples of mechanical mixtures, the fourth homework question:

Teacher: What's a mechanical mixture or an example of one?

Student 1: Cereal with milk?

Teacher: Okay cereal with milk. Maybe even the cereal itself is a mixture. That right? Especially say something like granola. Right? Different things in there. Another one?

Student 2: Sand.

Teacher: Okay. Sure. Yeah. Good. Beach sand. Sure. You've got bits of shells, different colored stones, bits of wood. All kinds of stuff in sand so there you go. Unless it's absolutely pure single component sand, but you don't run into that very often. Okay? Mixtures. Mixtures you can usually see the individual components... and often you can separate them.

Through his discourse, he defined mechanical mixtures as something which contains various components, each of which can been seen and separated from the other components. Rather than using a possessive relational process (e.g., a mechanical mixture contains two or more components which can be seen and separated), however, Mr. Peterson chose the human participant, *you,* with mental and material processes *(see, separate),* thereby involving the students more directly into the definition. He then asked the students how to separate various mixtures, beginning with a sand and salt mixture, a mixture which also brought in the concept of solution. As this was soon after he led the discussion about solutions, the responses to his question were quick:

| | |
|---|---|
| Teacher: | How would you separate a sand and salt mixture? |
| Tina: | Oh put it in water. |
| Teacher: | So say I got some salt. I got some sand and I pour them both together and I mix them up. And your job is to separate them into individual components. |
| Student: | Oh I know. I know! |
| Teacher: | Now Tina, you had an idea. |
| Tina: | Yeah. You put it in water and then |
| Teacher: | Yeah so |
| Tina: | Then you have salt water. |
| Teacher: | Good. So you got sand and salt water. I still want them in separate piles. That's a good start. Now what do you do? |
| Tina: | Well you can't because the salt's already melted in the water. |
| Teacher: | Melted? |
| Tina: | Not melted. Dissolved. |

Mr. Peterson probed to find out how the salt water could be separated from the sand, and through his questioning, he led the students to the answer. He also ensured that they were using technical terminology for the examples they were giving, as he did with Tina above.

He followed the example above by asking students how to separate oil and water, then how to separate sand, salt, gold, and iron, and finally how to separate alcohol and water. Each problem-solving activity was done through the same style of teacher-led discussion in which questions were asked of the students.

In the second example of separation, Mr. Peterson asked the students why oil floats, and in doing so, brought up the concept of density and the list of physical properties:

Teacher: Oil floats to the top. How come it floats?

Students: Density.

Teacher: Less dense. That's right. Oil is. It's thicker. What's the term for thickness again? Remember that? Thickness of a liquid. There's a term that applies to that. It was one of our physical properties.

He then quickly reviewed his list of properties before asking the students how they would separate the four components of salt, sand, gold, and iron, stating that the pieces are all the same size. He told the students to consider the physical properties of each component to figure out the answer:

Teacher: Now your job is to separate them into four piles. How would you do that? There's the thinking science nine students' way… and then there's the extremely tedious well you could get a microscope or a magnifying glass and a pair of tweezers and you pick out all the things—it'd take you forever! Especially if there's a big pile of them. So. It's important that you do it in the right order actually I think. You gotta think which one do I do first. Hint? Physical properties. That's how you do it. Think physical properties. What's the physical property this stuff has that the others don't. That's how you do it.

As before, Mr. Peterson used questions to help the students until they found the way to separate all four components. He reminded them about the physical property of each component (magnetic attraction, solubility, density). As he led the discussion, he wrote the answers on the overhead projector. Figure 6.7 shows the finished answer.

**Figure 6.7: Mechanical mixture separation**

sand, salt, gold, iron (same size particles)

1. magnet (iron)
2. add $H_2O$ (salt water + sand/gold)

   ↘ evaporate

   ↘ salt

3. panning — separate gold from sand

   much more dense

Not only did Mr. Peterson reinforce technicality during this session as shown by his response to Tina's use of *melting* instead of *dissolved,* he contrasted the scientific way of solving the problem—using their knowledge of physical properties—with an everyday approach of looking and sorting. Yet had the students not learned about the various physical properties, they may not have been able to solve the separation problem. Therefore, he demonstrated that to understand the concept of mixtures in a scientific way, the students must have a solid taxonomy of physical properties in their minds.

The final problem Mr. Peterson had the students solve through this teacher-led discussion was the separation of alcohol and water. Once again he made connections between the problem and the list of physical properties. He drew a diagram of the distillation process on the overhead projector, and included the boiling points of each. He also told the students the same distilling process could be used to separate salt and water, then asked them which countries would most benefit from this type of process, thereby allowing students to bring in their background, non-science, knowledge about geography.

In sum, Mr. Peterson's teaching of mixtures involved expanding on the taxonomy of matter presented early in the students' textbook by offering more examples and making connections between mixtures and physical properties. The examples presented can be divided into two types: those which were unfamiliar to the students, and those which were based on the students' existing knowledge. Examples of the first type—chemical solutions—were physically shown to the students, while those of the second type—granola, sugar water, salt water, and so on—were discussed. By bringing in the students' existing knowledge and their suggestions, Mr. Peterson was able to link the new ideas to students' current understanding and build technicality.

Mixtures were presented in a similar way to compounds, first by discussing examples, then by discussing the components, and finally by asking questions which promote logical reasoning:

1. Discusses examples. *(X is a kind of Y.)*
2. Examines components. *(X is made up of Y.)*
    - The components in solutions cannot be seen.
    - The components in mechanical mixtures can be seen and separated.

3. Provides problem-solving task.
   - Solutions are clear because... *(X because Y.)*
   - Mechanical mixtures can be separated by... *(X is a step in Y; X is a means to Y.)*

The first two steps, as with the discussion of compounds, addressed the taxonomic aspects of the concept. Step three, the problem-solving stage, used technical terms and concepts which Mr. Peterson had built up or reviewed as he discussed the components in step two. The move, therefore, went from building technicality to using this technicality in logical reasoning and sequencing.

### 6.4 The language of the interviews

On various occasions at lunchtime, starting in mid-October after the students had been studying chemistry and doing experiments for over a month, nine students began meeting with the researcher to talk about the work they had been doing in class. As Table 6.3 shows, these interviews were carried out either individually or with pairs of students.

**Table 6.3: The interviews with Mr. Peterson's students**

| Student interviews | Date |
|---|---|
| Ivan and Zachary | October 11, November 15 |
| Sara and Jeanie | October 17, November 15 |
| Mark | October 22 |
| Heather | October 22 |
| Stella and Andrea | October 30 |
| Edward | November 1 |

With the pairs, as chapter three detailed, the researcher asked the students to discuss together in her absence the experiments they had done, and then to call her over and tell her about these experiments and answer any questions which arose from the retelling. All students interviewed were asked about their first lab, Observing Changes in Matter, and the two demonstrations which aimed to illustrate the Law of Conservation of Mass. Two pairs of students participated in a follow-up interview which revolved around the second lab, Energy Stored in Food, and three demonstrations: liquid nitrogen, exothermic reactions, and endothermic reactions. In other words, six interviews targeted three tasks and two interviews targeted four tasks. These interviews offer a rich database for exploring the students' resources for talking about science.

### 6.4.1 Opportunities for technicality: The breadth of process lexis

A noticeable feature of the students' discourse was the breadth of the process lexis. As Table 6.4 shows, the nine students who were interviewed used a total of 195 different processes representing nine categories. Material processes accounted for the highest percentage (58.97%), reflecting to a great extent the recount tasks the students were doing as they told the researcher what they and their teacher had done in the experiments and the demonstrations. Material processes were followed in frequency by mental processes (12.31%), relational processes (11.28%), causal processes (6.67%), verbal processes (3.59%), temporal and behavioral processes (2.05% each), and existential and evidence processes (1.54% each).

In most of the process types, the students demonstrated that they had the linguistic resources needed to choose between two or more similar processes to construct similar meanings. While this ability to rephrase will be discussed in more detail later, examples which are based primarily on lexical choice are offered here to illustrate these resources:

Causal processes

| | | |
|---|---|---|
| 1a. | Sara: | It *produced* gas. |
| b. | Mark: | It *gave off* a gas. |
| c. | Mark: | It *released* carbon dioxide. |
| 2a. | Mark: | It *produced* heat. |
| b. | Ivan: | The chemicals with the water *generated* the heat. |
| c. | Ivan: | It *makes* it hotter. |
| d. | Ivan: | It'll *give off* heat energy. |

Processes of evidence

| | | |
|---|---|---|
| 4a. | Edward: | That *proved* the Law of Conservation of Mass. |
| b. | Edward: | It *showed* the Law of Conservation of Mass. |

Material processes

| | | |
|---|---|---|
| 5a. | Sara: | Mr. Peterson *did* another experiment. |
| b. | Sara: | He *conducted* another experiment. |
| 6a. | Mark: | We *measured* the mass. |

## Table 6.4: The 195 processes used by Mr. Peterson's students in the interviews

### Causal processes (13; 6.67%)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| cause | 5 | get | 3 | give out | 2 | release | 2 | tried to have (=tried to create) | 1 |
| create | 3 | generate | 1 | make | 3 | shoot off | 1 | turn out that | 1 |
| form | 3 | give off | 8 | produce | 13 | | | | |

### Temporal processes (4; 2.05%)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **begin** fizzing | 1 | **end up** | 1 | **start** to bubble | 1 | **start** to fizz | 1 | **start** to smoke | 1 |
| **end** | 1 | **start** bubbling | 1 | **start** to deteriorate | 1 | **start** to get warm | 1 | **start** working | 1 |

### Processes of evidence (3; 1.54%)

| | | | | | |
|---|---|---|---|---|---|
| prove | 2 | show | 3 | determine | 4 |

### Material processes (115; 58.97%)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| absorb | 1 | disappear | 3 | get | 11 | make sure | 3 | spark | 1 |
| add | 11 | discover | 1 | get out | 1 | measure | 11 | squeeze | 1 |
| attract | 3 | disintegrate | 4 | get to light | 1 | melt | 3 | stand | 1 |
| block | 1 | dissolve | 6 | get to play | 1 | minus | 1 | stay | 1 |
| boil | 1 | do | 49 | get stripped off | 2 | miss | 1 | steal | 2 |
| break | 1 | donate | 1 | give | 2 | mix | 18 | strike | 1 |
| bubble | 5 | drip | 1 | glow | 1 | need to cancel | 1 | switch | 3 |
| build | 2 | drop | 5 | go | 16 | off (=turn off) | 1 | take | 19 |
| burn | 4 | escape | 5 | go to get | 1 | place | 1 | tend to escape | 1 |
| cap | 1 | evaporate | 3 | have (=put) | 1 | plug | 1 | tilt | 1 |
| catch | 1 | explode | 1 | heat | 18 | pop | 2 | tip | 2 |
| change | 14 | fall | 2 | help | 1 | pour | 14 | transfer | 2 |
| close | 1 | fall off | 2 | hit | 3 | push | 1 | trap | 2 |
| combine | 3 | fiddle | 1 | hold | 1 | put | 68 | try to escape | 3 |
| come | 8 | find | 1 | improvise | 1 | react | 8 | try to make sure | 1 |
| come out | 1 | fizz | 11 | jump | 1 | reflect | 2 | turn | 10 |
| condense | 2 | flip | 1 | keep | 2 | repel | 1 | wait | 3 |
| conduct | 7 | float | 3 | leave | 1 | rise | 3 | warm | 1 |
| contradict | 1 | flow | 1 | let | 5 | shake | 5 | weigh | 21 |
| cool | 1 | fluctuate | 1 | let cool | 1 | shatter | 2 | work | 3 |
| cool off | 1 | fly | 1 | light | 11 | shield | 1 | wrap | 2 |
| corrode | 1 | freeze | 12 | look for | 1 | slide | 1 | write | 2 |
| crack | 2 | gain | 2 | lose | 5 | smash | 2 | use | 12 |

### Relational processes (22; 11.28%)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| be | 211 | consist of | 1 | go | 9 | look like | 3 | take | 2 |
| be called | 3 | equal | 2 | have | 24 | need to come out | 1 | take place | 2 |
| be stored | 2 | feel | 1 | hold | 1 | seem | 2 | turn | 47 |
| become | 7 | get | 25 | look | 1 | seem to have lost | 1 | weigh | 5 |
| call | 1 | give (time) | 1 | | | | | | |

### Mental processes (24; 12.31%)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| agree | 1 | figure out | 2 | hear | 1 | remember | 15 | unexpect | 1 |
| amaze | 1 | forget | 2 | judge | 1 | see | 6 | want | 2 |
| assume | 1 | get | 2 | know | 20 | think | 21 | want to hear | 1 |
| compare | 1 | guess | 1 | mean | 3 | try to figure out | 1 | want to make | 1 |
| expect | 2 | have (=know) | 1 | need | 2 | try to remember | 1 | | |

### Verbal processes (7; 3.59%)

| | | | |
|---|---|---|---|
| call | 1 | show | 5 |
| describe | 2 | tell | 4 |
| get over | 1 | yell | 1 |
| say | 5 | | |

### Behavioral processes (4; 2.05%)

| | | | |
|---|---|---|---|
| observe | 1 | talk | 6 |
| smell | 1 | watch | 4 |

### Existential processes (3; 1.54%)

| | |
|---|---|
| happen | 10 |
| occur | 2 |
| there is / are | 17 |

| | | |
|---|---|---|
| b. | Mark: | We *weighed* it again. |
| 7a. | Edward: | You *combine* it and get the new product. |
| b. | Edward: | When he *mixed* them it turned into a yellow substance. |
| c. | Edward: | We *poured* them *together.* |

Relational processes

| | | |
|---|---|---|
| 8a. | Mark: | The crystals that were blue *turned* white. |
| b. | Ivan: | They *became* white. |
| c. | Mark: | The heat caused it to *go* a silvery color. |
| 9a. | Ivan: | It *becomes* hot. |
| b. | Ivan: | It *got* warmer. |

Verbal processes

| | | |
|---|---|---|
| 10a. | Sara: | He *told* us that... |
| b. | Sara: | He *said* that... |

Using a variety of process types

| | | |
|---|---|---|
| 11a. | Sara: | We were doing the experiment and we *tried to figure out* how much energy was stored in food. (Mental) |
| b. | Sara: | We conducted an experiment to *determine* as to how much energy was in a piece of food. (Evidence) |
| 12a. | Sara: | This one *consisted of* potassium iodide and lead two nitrate. (Relational) |
| b. | Sara: | We *used* hydrochloric acid. (Material) |
| c. | Sara: | We *did* hydrochloric acid in sodium hydrogen. (Material) |

This variety of processes is noticeable in Table 6.4, but it is more clearly revealed by looking at the average number of occurrences per process. In other words, if the students have three different causal processes to create similar causal constructions, as the previous examples with Sara and Mark showed, and the number of clauses they constructed was three, the average number of occurrences per clause would be one, suggesting a broad variety of processes exhibited. A high number of occurrences per process suggests a higher reliance on that particular process. Table 6.5 presents the data in this way. It shows that the students relied on three existential processes to construct 29 existential clauses, or an average of 9.67 clauses for each different existential process, and 22 different relational processes to construct 352 clauses, or an average of 16 clauses for each relational process. Given the limited variety of possible existential and relational processes, these results do not challenge the idea that these students had a variety of resources at their command.

**Table 6.5: The average number of occurrences per process**

| Process type | No. of processes (total = 195) | | frequency (total = 1091) | | average number of occurrences per process |
|---|---|---|---|---|---|
| Causal | 13 | 6.67% | 46 | 4.22% | 3.54 |
| Temporal | 4 | 2.05% | 10 | .92% | 2.5 |
| Evidence | 3 | 1.54% | 9 | .82% | 3 |
| Material | 115 | 58.97% | 524 | 48.03% | 4.56 |
| Relational | 22 | 11.28% | 352 | 32.26% | 16 |
| Mental | 24 | 12.31% | 90 | 8.25% | 3.75 |
| Verbal | 7 | 3.59% | 19 | 1.74% | 2.71 |
| Behavioral | 4 | 2.05% | 12 | 1.1% | 3 |
| Existential | 3 | 1.54% | 29 | 2.66% | 9.67 |

At times, however, it seemed evident that some students were unaware of when their choice of processes was inappropriate. For example, when talking about what happened to the magnesium ribbon when it was immersed in hydrochloric acid, Andrea suggested that it *disappeared,* but her partner chose a different word:

Stella: Evaporated. Evaporated. Disappeared into the water.... It was pretty cool!

Ivan and Zachary chose a different yet still inappropriate process, *dissolve,* to talk about the fate of the magnesium ribbon:

Zachary: We take the magnesium ribbon and we put it in the hydrochloric acid.
Ivan: And then it dissolved.

Edward hedged somewhat on his use of *dissolve,* suggesting that he believed that whatever the ribbon did was similar in many ways to *dissolve:*

Edward: It seemed like it dissolved.

Neither *evaporate* nor *dissolve* are correct processes for describing what occurred, a point which Mr. Peterson had stressed in class. The students' choice of these terms instead of the correct term *react* suggests that they are unaware of the specific science meanings these words construct. Some students, however, have become aware of the need to use appropriate science terms, as Mark illustrated when he stated "Oh he's going to be yelling at me it's not weight, it's mass!"

### 6.4.2 The use of causal discourse in logical reasoning

The previous section noted that the students exhibited knowledge of a variety of processes with which to construct meaning. The types of processes the students chose influenced the extent to which their lines of meaning sounded causal. Take, for example, the following two excerpts:

Excerpt One:

| | |
|---|---|
| Stella: | And then with the um… one with the um… magnesium ribbon and the hy… drochloric acid… It like started to bubble and like started to smoke and it started to get warm and [it disappeared. |
| Andrea: | [And like there was some condensation. |

Excerpt Two:

| | |
|---|---|
| Mark: | Then… next… we… started working with the copper sulfate and we heated it and… it kind of turned— the crystals that were blue turned white and gave off a gas. We heated it again… and this time it produced more gas and went mostly white. When we added the water to the crystals it produced heat and became a liquid. |

In excerpt one, the listener hears that there are two entities involved—the magnesium ribbon and the hydrochloric acid—yet these become one, *it,* in the description of what happens. There is nothing in this text or in the prior discourse to indicate whether the joining of the two entities caused the list of events to occur. The listener hears only about the four events and the existence of the condensation, all joined with *and*, as Table 6.6 shows. Without a process in the first sentence and therefore no rheme, excerpt one has shown only the various effects of some unstated procedure without suggesting any causes for these effects. What exists is simply a list of events joined with the additive conjunction *and.*

**Table 6.6: The textual analysis of excerpt one**

| Conjunction | Topical theme | Rheme | Clause type |
|---|---|---|---|
| and then with | the magnesium ribbon and the hydrochloric acid | | |
| | It | started to bubble | event |
| and | | started to smoke | event |
| and | it | started to get warm | event |
| and | it | disappeared. | event |
| And | there | was some condensation. | existence |

In excerpt two, Mark is clearer about what has occurred and what causes what. The listener knows that Mark and his fellow students heated the copper sulfate (an action) which resulted in various events and causal actions. As Table 6.6 and Table 6.7 show, both texts use primarily additive conjunctions, but compared to Stella and Andrea's discourse, Mark constructed a text full of action and causality through the processes he chose. Although the causal links remain implicit, someone listening to Mark's discourse can better infer which actions have created which results. Much more guesswork is involved in getting the same implications from Stella and Andrea's text.

**Table 6.7: The textual analysis of excerpt two**

| Conjunction | Topical theme | Rheme | Clause type |
|---|---|---|---|
| | We | started working with the copper sulfate | event |
| and | we | heated it | action |
| and | it | turned white | event |
| and | | gave off a gas. | causal action |
| | We | heated it again | action |
| and | it | produced more gas | causal action |
| and | | went mostly white. | event |
| When | we | added the water | action |
| | it | produced heat | causal action |
| and | | became a liquid. | event |

The additive conjunction *and* joined the more temporal *and then* as the most common forms of conjunctions in the students' attempts to recount what had been done and explain what their experiments had shown. The term *and then* was used 112 times and *and* was used 94 times. Both were used to sequence events:

| | |
|---|---|
| Edward: | We put in some wa we dropped water into it? *And* the water turned bluish. |
| Mark: | It shoots off a spark *and* lights the gas. |
| Zachary: | The pressure would build *and* pop off the top *and* it would escape. |
| Sara: | He shook it up *and then* it changed. |
| Jeanie: | *And then* we added water *and* they became... more blue and... uh heat was produced. |
| Ivan: | *And then* it started bubbling and fizzing *and then* it becomes hot. |
| Andrea: | It went into the hydrochloric acid *and then*... it started to like deteriorate and like bubble and steam occurred. |

As the examples above show, *and* was used in a way that strongly suggested a time sequence as well as in ways which provided a weaker interpretation of time. Edward's observation shows a clear temporal relation in which the water was added before it turned blue; in fact, Edward's sentence implies that the addition of the water to the crystals could be the cause of the water turning blue, creating a subtle causal quality. This subtle causal interpretation occurs also in Mark's and Zachary's examples. Jeanie's use of the temporal *and* in her second clause mirrors Edward's, but the *and* which joins her second clause with her third is not as clearly temporal. The listener has no way of determining whether the blueness and the heat occurred at the same time without asking or without having witnessed the experiment. Ivan solved this by choosing to use *and then,* clearly marking a time difference between the fizzing and the heat production. Andrea's use of *and* to conjoin the deteriorating, the bubbling, and the steam offers no suggestion of causality and lacks a clear temporal implication. The *and* in her example simply shows a list of events which the listener must interpret as occurring either simultaneously or sequentially; knowledge of the experiments and what occurred in the class is needed for the interpretation.

In general, conjunctions associated with time were the most popular choices of these students, with fourteen different conjunctions used in the 366 temporal constructions containing them, as Table 6.8 illustrates. As noted above, *and then* was the most common of all conjunctions used (112; 24.1%), followed by examples of temporal *and* (94; 20.48%), the temporal conjunction *then* (62; 13.5%), and *when* in adverbial clauses of time (40; 8.71%). Some of these *when*-clauses were strictly time related, as in Mark's comment that "when we weighed it again it lost weight." There is no potential cause and effect relation here; weighing an item does not lead to its loss of mass. But Mark's comment that "when we added the water to the crystals it produced heat" allows for a causal interpretation. Adding the water may indeed lead to the heat production, but Mark's choice of the temporal conjunction *when* does not guarantee a causal connection. Out of the 40 examples of *when*-clauses which occurred during the interviews, 23 (57.5%) could be interpreted in a causal manner and 17 (42.5%) were strictly temporal.

Compared to the 14 temporal conjunctions, there were only 10 conjunctions typically associated with cause, and these accounted for only 93 constructions. The most frequently used of these was *because* (30; 6.54% of all conjunctions used), followed closely by *so* (29; 6.32%), the latter form appearing in adverbial clauses of result:

Edward: And the water turned bluish... probably *because* it was dissolving the crystals.

Zachary: And then he measured it again and it was supposed to be the same? *Because* the Law of Conservation of Mass holds?

Sara: It's a gas *so* it's going to float away.

Stella: Yeah cuz it was... it wasn't in a rubber test tube like the other one... *so* everything was kept in.

Unlike the situation with the primary students in which the teacher or researcher often asked the question *why* to prompt a *because* response, the students in these high school interviews did not typically wait to be asked. Only five constructions containing temporal or causal constructions involved the interviewer, suggesting that the students were easily able to offer insights on what they had done in class and what they felt they had learned.

As Table 6.8 shows, the students used a variety of causal processes of which most could construct causal actions such as *X causes Y.* Of these processes, *produce* was the most common (13), followed by the more everyday process *give off.* As shown earlier in the discussion of the variety of processes used, these two terms were used in similar constructions, usually with *heat* or *gas*.

## Table 6.8: The causal features of the mainstream interviews

| **Language Features Associated with TIME** | no. of times |
|---|---|
| after | 8 |
| afterwards | 4 |
| and | 94 |
| and then | 112 |
| as | 1 |
| before | 7 |
| first | 22 |
| later | 1 |
| next | 2 |
| so then | 9 |
| still | 2 |
| then | 62 |
| until | 2 |
| when | 40 |
| **TIME participants (14)*** | 18 |
| **TEMPORAL processes** | |
| begin | 1 |
| end | 2 |
| start | 7 |
| **TIME circumstances (7)** | 12 |
| **PLACE circumstances** | 150 |

*Numbers in parentheses indicate types rather than tokens.

| **Language Features Associated with CAUSE** | no. of times |
|---|---|
| although | 1 |
| because | 30 |
| if | 13 |
| so | 29 |
| so that | 6 |
| therefore | 2 |
| to | 6 |
| unless | 3 |
| whatever | 1 |
| without | 2 |
| **CAUSAL processes** | |
| cause | 5 |
| create | 3 |
| form | 3 |
| get | 3 |
| generate | 1 |
| give off | 8 |
| give out | 2 |
| make | 3 |
| produce | 13 |
| release | 2 |
| shoot off | 1 |
| tried to have (=create) | 1 |
| turn out that | 1 |
| **CAUSE participants** | |
| change | 16 |
| effect | 2 |
| product | 7 |
| reactant | 7 |
| **MEANS circumstances** | |
| with the peanut | 1 |
| with the hammer | 2 |
| with the tongs | 1 |

| **Other Language Features of Academic Explanations** | no. of times |
|---|---|
| **PASSIVE VOICE** | |
| broken | 1 |
| called | 2 |
| closed | 1 |
| created | 1 |
| frozen | 2 |
| kept | 1 |
| left | 1 |
| lit | 1 |
| lost | 1 |
| mixed | 1 |
| produced | 3 |
| reflected | 1 |
| stored | 2 |
| stripped | 1 |
| supposed *(fact)* | 6 |
| supposed *(prediction)* | 3 |
| taken | 1 |
| trapped | 2 |
| unexpected | 1 |
| **ENTITIES** | |
| metaphoric processual (25) | 86 |
| metaphoric quality (5) | 64 |
| abstract technical (19) | 63 |
| concrete specialized (39) | 275 |
| abstract semiotic (1) | 9 |
| **TECHNICAL processes (10)** | 29 |
| **TECHNICAL attributes (2)** | 7 |
| **LEXICAL DENSITY** | 39.2 |

The term *produce* was also used in the passive on three occasions. Yet of the 19 different passive processes, the most common to appear was *supposed,* particularly in clauses such as "we were supposed to make a table," which have been labeled as "fact." This use of *supposed* contrasts with comments such as "it was supposed to be the same," which have been labeled "prediction." The contrast exists in meaning, where the former refers to something the students were asked to do, and the latter to something that was predicted to occur but didn't. The contrast can be seen in Stella and Andrea's comments about lighting the Bunsen burner, a task with they had trouble with:

> Stella: You're supposed to let out the gas... and then you're supposed to take the [sparker
> Andrea: [I don't know.
> Stella: and you're supposed to like... and it's supposed to light but... you know.
> Researcher: But you couldn't get it to light.
> Stella: Oh no. We couldn't get it to light.
> Andrea: It's too scary.

The girls knew the procedures for lighting the burner (the "facts") and used the generalized "you" to offer instructions, but their use of *supposed* to show what the burner should have done suggested that their prediction did not occur as they had expected. This use of a human actor to refer to the "facts" and a non-human actor to present "predictions" which did not materialize was consistent throughout the data. Classifying *supposed* as a passive preserves the notion that *one supposes* that the students will follow directions, and *one supposes* that their predictions will be played out.

Whereas Table 6.8 presents a list of features which occurred in the interviews, Table 6.9 offers a view of how temporal and causal relations were constructed using several of the conjunctions and shows more clearly the relations which are considered more metaphorical. The table reveals that the students largely preferred to use congruent language to talk about science, using only seven of the less congruent forms to construct 51 of the 449 relations (11.36%). Furthermore, as previously noted, they did not typically require the researcher to co-construct these relations. Moreover, the table shows that the students here usually constructed relations in the positive; only eleven of the 449 relations (2.45%) used overtly negative forms such as "he just let it near so it wasn't dangerous" (X so not Y) or "both are suspended substances if you can't see the particles inside" (X if not Y).

**Table 6.9: Temporal and causal relations in the mainstream interviews**

| | | | |
|---|---|---|---|
| X because Y | 24 | if X, then Y | 7 |
| (X)* because Y | 2 | if X, then not Y | 1 |
| X because not Y | 1 | X if Y | 4 |
| X, so Y | 27 | X if not Y | 1 |
| X, so then Y | 9 | when X, then Y | 30 |
| X, so not Y | 3 | (when X), then Y | 3 |
| not X, so Y | 1 | when X, then not Y | 1 |
| X so that Y | 6 | X when Y | 6 |
| X, therefore Y | 2 | X, then Y | 62 |
| X, and Y | 91 | X, and then Y | 112 |
| X, and not Y | 3 | do X and Y happens | 2 |

**Less congruent forms**

| | |
|---|---|
| X to do Y | 6 |
| to do X, Y | 1 |
| without X, Y | 2 |
| X unless Y | 3 |
| X "causes" Y** | 30 |
| X "causes" Y to Z | 5 |
| X is "caused" | 4 |

*Items in parentheses indicate researcher.

**The notion of cause was constructed by various processes.

### 6.4.3 Shifting between the congruent and the metaphoric

The students interviewed seemed well able to move between congruent meanings and more grammatically metaphoric forms. The discourse revealed this in a variety of ways. One way, as earlier mentioned, was through the construction of causal actions instead of the statement of events. In this way, the causal meaning is construed through the choice of process, making the construction more metaphoric compared to the event, a congruent comment of the happening. Another way the students showed their ability with grammatical metaphor was revealed through the students' use of nominalizations. This move from congruent events to nominal groups and to actions surfaces in the many ways which students talked about temperature change. In Figure 6.8, Zachary, Ivan, Andrea, Stella, Sara, and Jeanie all offered congruent descriptions of what had occurred in one of their experiments. These descriptions were stated as events. Edward also uttered an event, but rather than describing the event in terms of adjectives as the others had done, he offered "a low temperature change," a nominalization which was ambiguous in that the listener could not determine whether the change was upward or downward. Mark construed the event as an action, suggesting that "it" (adding the water to the crystals, constructed as a *when*-clause) produced heat:

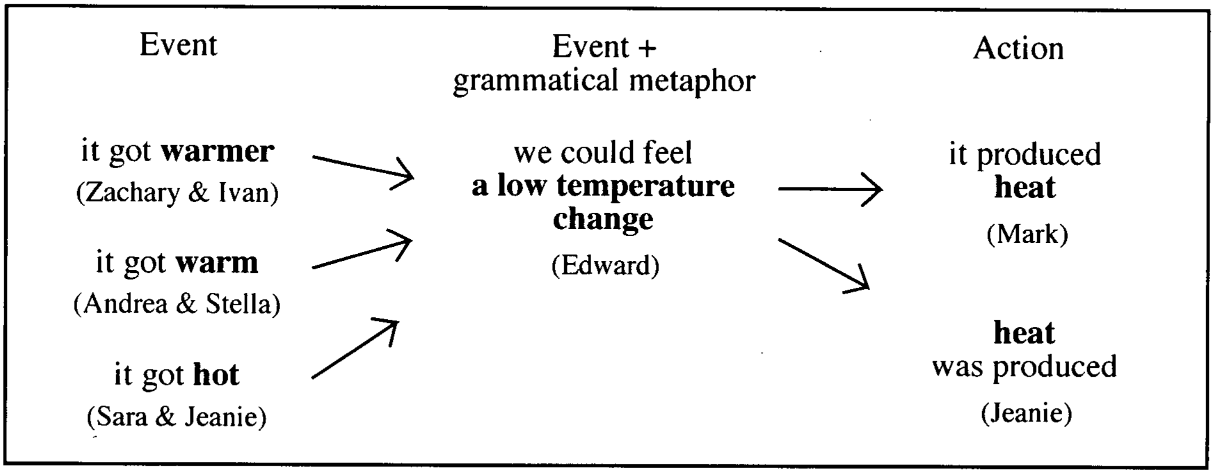
Mark: Then we added the water... and... when we added the water to the crystals it produced heat and became a liquid.

Jeanie went one step further into grammatical metaphor by turning the action into the passive:

Jeanie: And then we added water and they became... more blue and... uh heat... heat was produced.

Jeanie used the nominalization *heat,* which Martin (1997) would term metaphoric quality with the passive form of a causal process where she had earlier constructed an event with no nominalizations.

**Figure 6.8: Shifting from events to actions**




Despite the causal quality that actions appear to create in the explanations, they were used less than one quarter as often as events were in the students' discourse. Out of the 1091 clauses constructed, 224 (20.53%) were events and only 60 (5.5%) were actions. The balance fell into neither category and included such constructions as relational clauses and projections.

Shifting between more congruent and less congruent forms appeared to be quite natural for these students. Sara, while talking with Jeanie about what they had done in their experiment, made the following statement:

Sara: So the point of our experiment was to judge whether or not... um... a reaction occurred between substances.

A short while later, as the girls presented their ideas to the researcher, her parallel utterance had become much more congruent:

Sara: So we did this experiment... to observe some substances and how they reacted with each other.

the point of our experiment (metaphoric) → so we did this experiment to (congruent)

whether a reaction occurred (metaphoric) → how they reacted (congruent)

Sara appeared to move easily back and forth and did not seem to base her choices on the audience. Moreover, she used nominalization colloquially to express her lack of understanding of how to operate the Bunsen burner:

Sara: And I totally didn't get the whole... gas down here and gas up here thing.

Sara could have stated that she did not understand how to adjust the gas and air flow to make the burner work, but she instead turned what could have been her clause (how to adjust the gas and air flow) into a context-dependent nominalization: "the whole gas down here and gas up here thing." The result does not sound scientific or academic, but it does illustrate Sara's ease with language.

Edward used grammatical metaphor to define a science term which was relevant to the experiment he had witnessed:

Edward: When he mixed them... it turned into a yellow substance and he called— he told us that um... when something changes color and produces some sort of powder that's called a precipitation reaction? And it's not gas producing. It's just that... it just produces a solid?

Edward described the procedure and defined it by giving it a name, precipitation reaction, which was a nominalization representing the procedure:

something changes color and produces a powder → precipitation reaction

process (action) → nominalization (thing)

He then rephrased his definition by clarifying that the precipitation reaction is not gas-producing, "it just produces a solid" (the powder). Edward therefore went from the more congruent procedure to the highly metaphoric scientific term, then shifted back to a greater level of congruency, again illustrating the relative ease with which these students seemed to move back and forth between the congruent and the metaphoric.

Edward's turning of a process into a nominalization as he did with *precipitation reaction* creates what Martin (1997) referred to as *metaphoric processual entities,* and as Table 6.8 shows, the students used 25 of these in a total of 86 occurrences. Due to the goals of the experiments, metaphoric processual entities concerned with various types of reactions (precipitation, gas-producing, exothermic, and so on) accounted for 21 occurrences, with *reaction* by itself accounting for ten of these. The table also indicates that there were five entities which Martin would classify as *metaphoric quality* used on 64 occasions, which *mass* and *heat* the most popular in that category. There were 19 abstract technical terms occurring a total of 63 times, but the most popular entities associated with the science content were concrete specialized terms (39), which accounted for 275 entities. A list of these entities with their frequencies can be found in Appendix 5.

Relating actions with things, as Edward did above by using the present tense passive relational process *is called,* reflects a timeless generalization about the topic rather than a specific observable event. Although in the interviews, the discourse primarily involved recounting the events which had occurred in the experiments and demonstrations, the students were given opportunities to make generalizations about these events. For example, Zachary and Ivan were asked first to recount what they had done in their experiment, and when they were asked for their conclusions, they both made general knowledge claims:

Researcher: So tell me about the burning peanut.

Zachary: Well we um we put it on? We put it on the paper clip and then we stood it up into the Bunsen burner until it was... sort of on fire?

Ivan: And but then the peanut... the paper clip melted and the peanut fell. So we had to improvise and use the tongs to hold it up to the fire and then under the beaker.

Zachary: ... And we wrapped it with aluminum foil so that the heat that was trying to escape could get reflected in (xx).

*(A few turns later.)*

| | |
|---|---|
| Zachary: | Uh the temperature rised and then we just got the temperature... and did the math and we got the energy. And then we measured it. |
| *(A few turns later.)* | |
| Researcher: | Mm-hmm? What was your conclusion? |
| Zachary: | I got that if you measure a food or any other item they all give out as energy. Like heat? It's using some of the energy. It pushes the energy into the heat so it gives off energy. |
| *(A few turns later.)* | |
| Ivan: | When you... light any type of food on fire then... it'll give heat to us. It'll give off heat energy. |

Zachary's and Ivan's discourse up to the researcher's inquiry about conclusions reflected the specific events of the experiment, using the past tense to construct the recount. Their conclusions, however, involved into a factual conditional in the form of a causal *if*-clause (Zachary) and a temporal *when*-clause (Ivan). Zachary also exploited the timeless present tense to suggest that his conclusions were not specific to the event of the burning peanut, but to all events. Moreover, his choice of participants such as "a food or any other item" also showed a move from the specific experiment to a more generalized knowledge claim, as shown in Table 6.10.

**Table 6.10: Examples of specific and general in Zachary's and Ivan's discourse**

| **Specific** | **General** |
|---|---|
| Processes: | Processes: |
| past tense | factual conditionals |
| e.g., *stood* | e.g., *if you measure* |
| *was* | *when you light* |
| *melted* | timeless present tense |
| *fell* | e.g., *give out* |
| *wrapped* | *pushes* |
| | *gives off* |
| Participants: | Participants: |
| specific | general |
| e.g., *the peanut* | e.g., *a food* |
| *the paper clip* | *any other item* |
| *the heat that was trying to escape* | *heat energy* |
| | *any type of food* |
| | *energy* |

The students typically shifted from the past tense recount to the present tense generalization when they made connections between the events they had witnessed and the theory which the teacher was trying to illustrate. Sara and Jeanie, for example, used the past tense (marked in italics) to recount the demonstration which Mr. Peterson had done to illustrate the Law of Conservation of Mass, but the law itself was stated in general terms using the timeless present, as shown in bold face:

| | |
|---|---|
| Sara: | He *used* potassium iodide and lead two nitrate... and he *had* the lead... two nitrate in a... beaker sort of thing and the potassium iodide in a smaller test tube inside that beaker. |
| Researcher: | Mm-hmm? |
| Sara: | And he *had* the stopper on top. So he *weighed* it... and then he [*shook* it |
| Jeanie: | [*Shook* it. |
| Sara: | or *mixed* it? And they *reacted* and kind of like a... bright yellow liquid. |
| Researcher: | Mm-hmm. Mm-hmm. |
| Sara: | And that *was* totally wow. And then we *weighed* it again and it *was* exactly the same to the hundredth of a gram. |
| Researcher: | And what does that show? |
| Sara: | That... |
| **Jeanie:** | **The mass of the reactants is the same as the mass of the products. [Which is** |
| **Sara:** | **[That's the Law of the Conservation [of Mass.** |
| Jeanie: | [Of Mass. |
| Researcher: | Mm-hmm? |
| Sara: | So we *proved* it. |

Mark, however, fluctuated between making generalizations and keeping his knowledge claim anchored in the specific context. Just as Sara and Jeanie had done, Mark recounted the first demonstration using the past tense consistently, and when asked what the demonstration showed, he made a generalization:

| | |
|---|---|
| Researcher: | And what did that show? |
| Mark: | **Nothing escapes. You can't have mass that wasn't there before.** |

But after recounting the second, open experiment in which gas was produced, Mark kept his explanation more securely anchored in the context, using the exophoric "that" and the past tense:

Researcher: And what did that show?
Mark: That without that gas to measure there, we've lost mass... so we *weren't* measuring that so we the mass *was* less.

By using the present perfect and past tense rather than the timeless present, Mark appeared to have been offering this specific example of what had happened to the mass to show why the Law of Conservation of Mass had not been broken. He had, after all, already stated what the law was claiming in his earlier comment.

Whereas the two previous examples showed how the recount of the context interacted with the statement of the theory which the context illuminated, the following example shows how Edward used his existing theoretical knowledge to talk about a hypothetical situation:

Researcher: Um... what would have happened probably if Mr. Peterson had done the second experiment in a sealed container?
Edward: In a sealed container the— If it was glass it would probably crack... because the gas is like... when it forms it takes up space?
Researcher: Hm-hmm.
Edward: And it's trying to escape? When it's trying to escape it might crack the glass or it might cause it to explode somehow?

Edward used causal and temporal conjunctions to explain what the outcome of the action might be. His explanation could not be anchored in the here and now because such a context never existed for him in the classroom. Edward therefore drew upon his theoretical knowledge of chemistry ("when it *(gas)* forms it takes up space") in responding to the question. In other words, rather than relying on the recount of a specific action to illustrate a theory, Edward used his existing theory to speculate on a specific action. The students in this class appeared able to move between the congruent and the metaphoric, and between the specific and the general, relatively easily when the conversation required them to do so.

### 6.5 Summary

This chapter has attempted to explore both how Mr. Peterson constructed knowledge in his class by building technicality and prompting logical reasoning, and what the resources were that his students used to talk about what they had learned and done. This was examined closely through a detailed look at how he built up three concepts—physical properties, compounds, and mixtures. The concept map drawn from the discourse, following Novak

(1998) appears as Figure 6.9. In general, Mr. Peterson's method of teaching science was to elicit what the students knew, translate between whatever relevant everyday taxonomy they offered and the target technical terms, then use this new, technical taxonomy in discussions. The questions the teacher asked were not always concerned with science topics; he elicited whatever background knowledge he felt would help illustrate the concept he was presenting.

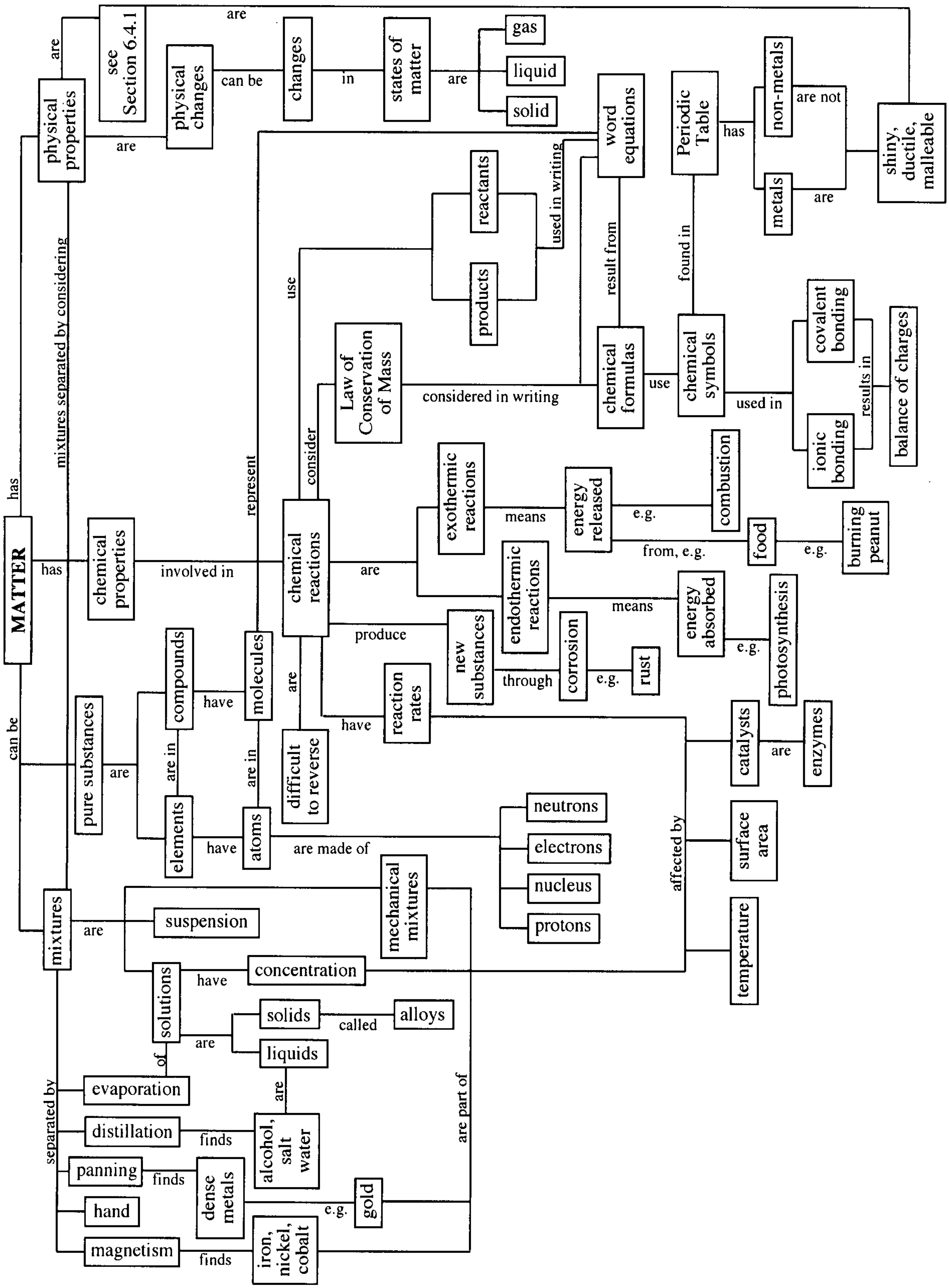
The three concepts described in detail in this chapter provided a foundation for much of the subsequent discussions on chemical bonding. They were introduced through the reading assignment which students did for homework, but taught in class by first asking for definitions and examples, then by building up taxonomies through these examples, and finally by using the technicality in logical reasoning. The technicality was built in three distinct ways: through experience, translation, and interlocking definitions. Mr. Peterson provided visual examples through demonstrations as well as through lab experiments so that the students could link new experiences onto the new technical terms. The mini-demonstrations of lead being whipped around against the teacher's hand to teach the concept of malleability is a simple example of this technical term/physical experience link.

Mr. Peterson also used translation to build technicality, by linking students' everyday understandings and examples to science terms. The physical properties of viscosity, for example, was linked in a token/value relation to thickness. In fact, many of the nominalizations which Mr. Peterson introduced were done using these translation methods of defining as he moved from the more congruent forms which the students offered or were expected to understand to the more grammatically metaphorical forms which reflected a higher level of technicality.

The teacher also related technical terms together in what Halliday (1993) referred to as interlocking definitions, yet he attempted to ensure that the students understood enough of some of the terms to make the new forms comprehensible. His construction of compounds and molecules by using elements and atoms was a clear example of this.

Mr. Peterson's most common way of prompting logical reasoning was to offer students problem-solving scenarios. These were often phrased in *if... then...* clauses, requiring the students to complete the second part of this causal construction. These scenarios were

**Figure 6.9: Mr. Peterson's unit as a concept map**



typically connected to physical properties, which offered students the means for solving problems in the wider field of chemistry that they were studying. Logical reasoning was also prompted by Mr. Peterson's use of *when... then...* (temporal) conjunctions, in which he would ask the students questions using the first clause (e.g., What happens to the viscosity of honey when the temperature goes down?). At this logical reasoning stage of the science lesson, Mr. Peterson expected the students to understand and use the technical terms he had presented, especially those which constructed a particular type of knowledge, such as using *dissolve* for solutions, rather than *melt.*

Mr. Peterson's use of technicality was reflected in the language which the students used as they discussed what they were learning in science. They attempted to use appropriate technical terms and exhibited 195 different processes representing nine categories from which to construct the meanings they wanted. The data showed, for example, 13 different causal processes, 3 processes of evidence, and 22 relational processes, key types of processes typical of science discourse.

Not all students were aware of the appropriate use of technical terms, however. Some, like Andrea and Stella, chose to talk about the process which occurred when magnesium ribbon was immersed in hydrochloric acid as *disappeared* or *evaporated.* Ivan described the reaction using the process *dissolve.* Edward hedged on the term by claiming that "it seemed like it dissolved," suggesting that he was aware that the term constructed a meaning which differed from the one he had witnessed. Mr. Peterson had stressed the importance of using the correct term in class, but many students struggled to remember how to explain what had happened, while others simply used their everyday understandings.

Regarding the use of causal markers in the students' interview discourse, the most common conjunction used to sequence events was *and then,* which occurred 112 times, followed by *and,* used 94 times. In general, conjunctions associated with time were the most popular choices, with 14 different conjunctions used in the 368 temporal conjunctions containing them. This contrasts with 10 conjunctions of cause used in only 94 causal conjunctions, of which the most frequent was *because* (30), followed closely by *so* (29). Instead of relying heavily on causal conjunctions, the students used 13 different causal processes to construct a causal line of meaning in their explanations. The process *produce* was the most common (13), followed by *give off* (8) and *cause* (5). Four different causal participants were also used on 32 occasions. Still, the data show that as a rule, the students preferred to use the more congruent forms when they talked about what they had learned about science.

The students who were interviewed showed that most were adept in shifting from the congruent to the grammatically metaphoric. Sara and Jeanie exhibited this on several occasions as they moved between events (e.g., "it got hot") and metaphoric actions (e.g., "heat was produced"), or between processes (e.g., "they reacted") and nominalizations of the process (e.g., "the reaction"). In fact, the students as a group used 24 different metaphoric processual entities in 85 occurrences, and five metaphoric qualities used on 64 occasions. Such usage suggests that these students were comfortable using grammatical metaphor in their explanations of science, showing that they had mastered Halliday's two levels of patterning for much of what Mr. Peterson had taught.

The reader may have noticed that utterances by Heather, the Korean student who was in Mr. Peterson's science class, did not appear in the discussion. As mentioned in Chapter 3, Heather was a relative newcomer to Canada and to the mainstream class at Western High School. She had arrived from Korea four months before the end of the previous school year and had participated in ESL Science for those four months before being placed in the mainstream grade nine class for the current school year. Although she was doing quite well on her assignments, and her overall performance in grade nine science at this time was considered average by the teacher, she never spoke out in class and had trouble finding lab partners because of her linguistic ability. She was enthusiastic about participating in an interview, but for the most part, her discourse remained highly congruent as she recounted the experiments and demonstrations in short, often incomplete utterances, highly supported by the researcher:

Heather: And... mag... magnesium ribbon?
Researcher: Mm-hmm?... What did you do with the magnesium?
Heather: Mm... we put in the other?
Researcher: Was it— *(Time passes.)*

Heather: Mm… uh… hydro hydrogen stuff.
Researcher: Yeah. You put it in the hydrochloric acid? Mm-hmm?
Heather: And… it's fizzing up and disappeared…. Mm.
Researcher: So it fizzed and disappeared… completely?
Heather: Mm-hmm.

On many occasions in the interview, Heather responded with comments such as "I don't remember" or "I don't know." Her struggle with the language and her limited resources for making meaning identified her as sounding more like the students in the ESL science class, which is the focus of the next chapter.

# CHAPTER 7: MS. ARMSTRONG'S HIGH SCHOOL SCIENCE CLASS

## 7.0 An overview of the chapter

Chapter 6 examined Mr. Peterson's mainstream chemistry unit, paying particular attention to the ways the teacher directed the construction of knowledge through classroom discussions and activities. Chapter 7 looks at Ms. Armstrong's ESL science class and, in a way that is similar to the earlier contexts, responds to the following research questions:

1. How do Ms. Armstrong and her students develop causal explanations and their relevant taxonomies through the classroom interactions?
2. What are the causal discourse features which Ms. Armstrong's students used to construct oral causal explanations?

Chapter 7 follows a similar pattern to the previous chapters. Section 7.1 offers an overview of the science unit, and Section 7.2 examines Ms. Armstrong's teacher-led lessons, describing how she attempted to build technicality and logical reasoning. Section 7.3 tracks the construction in class of the same three key concepts examined in Chapter 6: *physical properties, compounds,* and *mixtures.*

Section 7.4 looks at the interview sessions which five students participated in, highlighting the resources which these students relied on and the difficulties they encountered as they tried to articulate their understandings. The final section, Section 7.5, summarizes the chapter.

## 7.1 Ms. Armstrong's chemistry unit

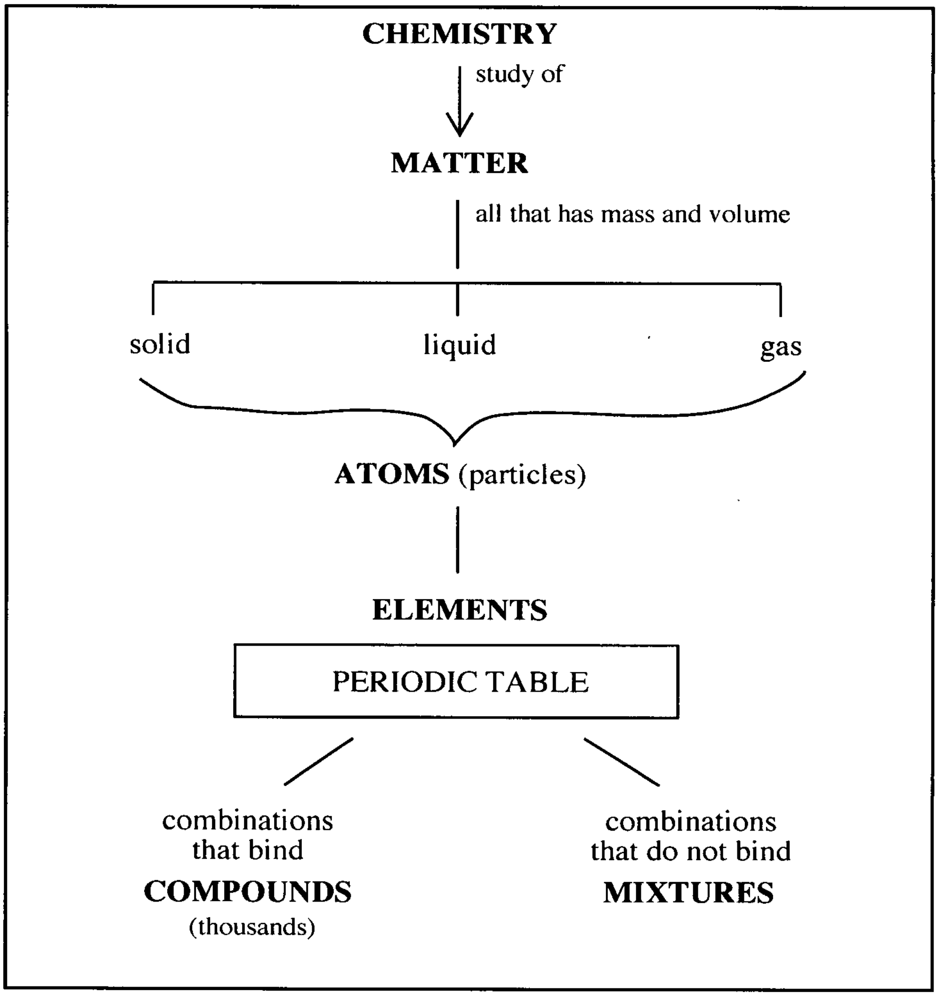
Before beginning a description of Ms. Armstrong's chemistry class, several important points need to be stated. As noted in chapter three, Ms. Armstrong was not a science specialist, although she had built up a good reputation as an ESL science teacher at Western High School over the years she had been there. The ESL science program, which she had been teaching, had been cancelled two years earlier, and was brought back for the current year because of the high number of ESL students who needed the support. All the science equipment which the teacher had collected for teaching the course had been returned when the program was cancelled, and she had not attempted to gather it all back for the current year for three main reasons: (1) She judged the current year's students to be too "immature" to work safely and properly with the equipment, (2) she was not convinced that the program would continue to be offered in the following year, and (3) she was not planning to remain at the school in the following year. Because of these reasons, she was left to rely heavily on the textbook she had chosen for the unit.

Ms. Armstrong's chemistry unit included topics such as physical and chemical properties and changes, matter, the atom, the periodic table, and bonding. The content was chosen from the grade eight and grade nine curriculum and reflected specific areas that the school's science department asked her to present as well as her own interests within the curriculum. Ms. Armstrong also aimed to address the science department's request to have the students practice thinking skills such as hypothesizing, concluding, and problem-solving as well as organizational and cooperative group skills, study skills, and writing lab reports.

Ms. Armstrong began the chemistry unit in January and continued through the topics until the end of the school year in June. The progression from one topic to the next is captured in Figure 7.1 with the teacher moving down from the topic of matter through to compounds and mixtures. This diagram was presented in early January, and the students were directed to create definitions for six of its terms: chemistry, matter, atoms, elements, compounds, and mixtures. Students were quizzed on these definitions on January 15th, and the terms were reviewed and defined again later as each topic was taught in greater detail. Highlights of the unit are shown in Table 7.1.

As the table indicates, Ms. Armstrong gave the students a quiz about every two to three weeks. The students carried out two labs and one observation exercise during the roughly five-month period, and did one creative writing activity based on their understanding of atoms. There was also one all-day field trip to a local science museum during which students were supposed to answer several pages of questions. Although the students were not told, these field trip questions were not going to be collected or graded, but were given primarily to keep them on task in the museum and to aid in preventing absenteeism. Aside from these highlighted activities, the students watched clips of two videos—one on the periodic table and one on chemical reactions—played two games to review content,

**Figure 7.1: Diagram of Ms. Armstrong's chemistry unit**




interacted with Ms. Armstrong in question-and-answer sessions, and did oral reading activities, group problem-solving, note-taking, and note copying. Small group activities, such as working together to define terms or to create and write practice quizzes, were carried out almost daily. The students typically talked in their first languages during these group-based activities.

Most classes began with a teacher-led question-and-answer session which reviewed the content presented earlier. This frequent review, also done through quizzes, seemed to suggest that memorizing specific content was an important goal, despite its absence from Ms. Armstrong's stated objectives. This may have been because the two ESL science classes were considered by Ms. Armstrong to be too "immature" to participate in her usual projects and activities:

> A lot of my decisions this year have been based on the immature level of my kids. *(She continues later.)* I just couldn't trust them with anything. I've done… compared to my usual program I've done half this year or maybe three quarters. Maybe half. (Interview with teacher)

The teacher's inability to trust her students to behave themselves during library visits and more complex labs in the science department prevented her from including those activities; it appears that oral reviews and other teacher-led tasks were used instead.

**Table 7.1: Major events in Ms. Armstrong's ESL science class**

| Dates | Task |
|---|---|
| January 15, 2001 | Quiz on basic definitions |
| February 1, 2001 | Quiz on matter (1) |
| February 5, 2001 | Lab: Is gas matter? |
| February 9, 2001 | Quiz on matter (2) |
| February 15, 2001 | Field trip to local science museum |
| February 28, 2001 | Quiz on the atom |
| March 12, 2001 | Writing activity: Help, I'm trapped inside an atom! |
| March 14, 2001 | Test on the atom |
| April 4, 2001 | Group quiz on the periodic table |
| April 12, 2001 | Observation activity: Describing elements |
| April 26, 2001 | Test on periodic table, elements, and atoms |
| May 16, 2001 | Quiz on mixtures and compounds |
| May 24, 2001 | Lab: Chromatography |
| June 1, 2001 | Test on mixtures and compounds |

Ms. Armstrong used a variety of material from photocopiable teacher resources as well as material she had developed herself. The textbook she relied on, *Chemistry* (Scott, 1987), was a discontinued resource which she chose because "it covers the concepts with very simple language. It's actually designed for slow learners" (interview with teacher). When Ms. Armstrong developed materials herself, her primary focus was to simplify the language so that the students would understand the concepts:

> I start with a unit that's from a grade eight or nine textbook. And the language is way too difficult. Otherwise they'd *(the students)* be in there *(grade eight or nine mainstream science)* so I have to simplify it. I often have just taken

> something directly out of the science eight or nine textbook and I simplify it myself. (Interview with teacher)

When asked whether she did this by creating key visuals or by rewriting, she stated that she typically rewrote the material. Most of the chemistry unit observed for this research, however, used the textbook, materials presented in visual format, and the teacher's oral explanations and analogies. Moreover, students created their own "chemistry dictionaries" by copying down definitions which they had created in groups, written on the blackboard, and which had subsequently been corrected for grammatical errors by Ms. Armstrong, who exhibited a strong focus-on-form approach to student-produced written text. Other handouts on how to construct definitions and write lab reports were also distributed to the students.

## 7.2 Constructing knowledge in Ms. Armstrong's class

The first thing that should be noted is that whenever the students were given the opportunity to work in groups on labs, problem-solving questions, or other group tasks, they would speak in their first languages with only occasional, task-specific English vocabulary uttered. It was only when the teacher or researcher approached the groups and asked questions that the students offered English responses. In groups where one or two students did not share the language of their group members, these students typically remained silent and often worked on the task alone. Ms. Armstrong frequently reminded all students that she "would like to hear some English," but this effort did not alter the situation. The opportunity to speak and listen to English was connected only to the teacher-fronted lectures and questioning techniques of which Ms. Armstrong made ample use.

### 7.2.1 Building technicality: Renaming, redefining, and reclassifying

Like Mr. Peterson, Ms. Armstrong asked various questions to promote interaction in the class, and the students' responses were typically short. Ms. Armstrong's most common purpose for questioning was to reinforce material which she had recently presented, typically by having students read aloud from the textbook and then asking questions about each small section read. The reinforcement of content was done as rapid oral review sessions, frequently at the beginning of class, and it involved either students calling out short, often one-word answers or raising their hands to be nominated to respond:

| | |
|---|---|
| Teacher: | Okay. I want to start with a review. Can I have everybody's attention? All right. What is an atom? And I want you to raise your hand. Okay? Brandon? |
| Brandon: | A small piece of matter. |
| Teacher: | Good. A small piece of matter. Name one... one... uh particle in an atom. One particle. One part of the atom. Okay. Tony? |
| Tony: | Proton. |
| Teacher: | Proton. Name another part of an atom... Ron? |
| Ron: | Neutron. |
| Teacher: | Neutron. Good. And the third part of an atom... Ron? |
| Ron: | Electron. |
| Teacher: | The electron. Good. |

This content had been presented in an earlier class and was aimed at reviewing the information.

Ms. Armstrong put a large emphasis on developing the students' ability to define science terms, and the students were often required to construct definitions using a formula which she had presented on information sheets distributed early in the school year and reviewed prior to asking students to define terms in working groups. The information given to the students emphasized the following pattern:

| | | | | | |
|---|---|---|---|---|---|
| | **Term** | **=** | **General Class Word** | **+** | **Specific Characteristics** |
| e.g., | Einstein | is/was | a scientist | who | discovered the theory of relativity. |
| | **Term** | **=** | **Specific Characteristics** | **+** | **General Class Word** |
| e.g., | Protozoa | are | one-celled | | animals. |

The whole-class review of this pattern was accomplished by the teacher's questions:

| | |
|---|---|
| Teacher: | What are the three parts of a definition? |
| Keith: | Term. |
| Teacher: | Term. And? |
| Students: | Class word. |
| Teacher: | Class word. And? |
| Fred: | Special characteristics. |
| Teacher: | Characteristics. Good. What does term mean? What is the term? |
| Fred: | The word are defining. |

| | |
|---|---|
| Teacher: | The word you are defining. Good. What is the class word? |
| Males: | The group word. |
| Teacher: | The group that it belongs to. And specific— What are characteristics? |
| Males: | How to describe it. |
| Teacher: | How you describe it. Excellent. |

After reviewing the parts of the definition, the teacher frequently had students work in groups to define specific science terms, and then had them write their definitions on the blackboard. She then corrected the grammar, spelling, and punctuation of the definitions before instructing the students to copy them into their chemistry dictionaries. These sessions were heavily focused on the form of the language rather than on the meaning, and this focus on form was a regular part of Ms. Armstrong's lessons.

The teacher also used students and items in the room to reinforce the pattern of the definition. On one occasion, she elicited a definition of Bert, one of the students in the class, by naming Bert as the term to be defined and asking for the class word, which was offered as student. Eliciting special characteristics took much more probing by the teacher as she requested "something that would be true of Bert but not true of everybody else." Although the suggestions made by the students created small taxonomies of characteristics or properties, Ms. Armstrong accepted only the responses that would distinguish Bert from all other students. The class finally agreed on the name of the school and Bert's student number. Similar review discussions were carried out to create a definition for other students and for an overhead projector pen. Each time, Ms. Armstrong compared the class-constructed example with the examples written on her information handout.

At times Ms. Armstrong chose one of the terms which she was assigning for definition and questioned the students orally so that a whole-class definition could be made:

| | |
|---|---|
| Teacher: | Say we're defining electrons. What word do you need between electrons and the class word? So electrons are the— is the term. What word means equals? What word goes between electrons and the class word? |
| Fred: | Is. |
| Teacher: | Is? But we've got electrons. |
| Males: | Are. |
| Teacher: | Okay. Electrons are or... an electron... |
| Males: | Is. |

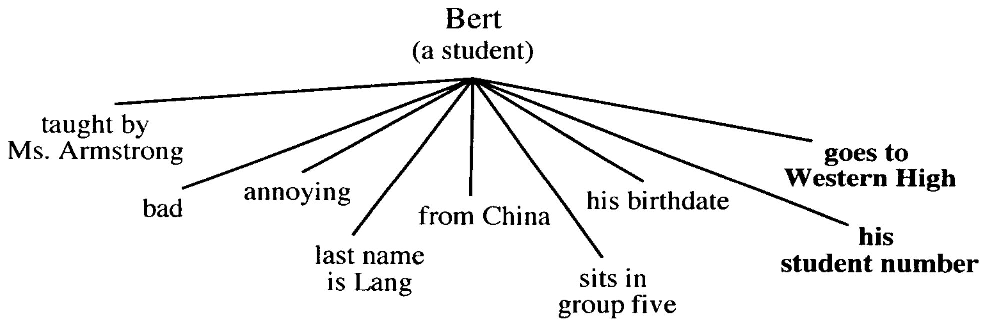
Ms. Armstrong continued by eliciting a class word which she agreed could be particle or part of an atom or particle in an atom. She then asked for special characteristics, and after several rejected attempts, the final part of the definition was arrived at:

| | |
|---|---|
| Rhonda: | Circle. |
| Teacher: | They circle the nucleus. That's one. Another one? |
| Fred: | Two thousand times smaller than proton. |
| Teacher: | Mm. Okay. Um yeah. All right. And they're... they have a negative charge. Those are the important characteristics. One. They have a negative charge. Two. They circle around the nucleus. Those are the important characteristics. |

Ms. Armstrong asked the students if they understood the task she had given them, then assigned them to groups to work on defining *nucleus, protons, neutrons,* and *electrons.* As previously mentioned, the definitions were then written on the blackboard by the students and corrected by the teacher who asked questions orally to highlight the grammatical problems and elicit the correct forms. Once they were corrected, the definitions became part of the questioning sessions in a later review or written quiz.

The formula for these definitions does not allow students to translate between everyday understandings and scientific taxonomies. The term to be defined, the class word, and the characteristics are all either related to science or related to the common-sense world, a situation which Ms. Armstrong capitalized on by using Bert, Cory, and pens to show definitions of everyday ideas, and electrons (and protozoa and other examples on the information sheet) to show that science definitions are done the same way. On the surface, this appears to be a useful way to bridge between the everyday and the scientific taxonomies, but what occurs can pose problems with interlocking definitions, which, according to Halliday (1993), can make science discourse difficult to understand. This can be illustrated more clearly by examining the taxonomies and definitions constructed in class. In the everyday taxonomy, Bert (an example of a student) is distinguished from all other students by having a particular student number at a particular school, with all the other suggested characteristics rejected from the taxonomy presented in Figure 7.2. To understand the definition of Bert, therefore, the students would need to understand what a student number is and what Western High is. These are interlocking definitions, but they are for common-sense information for these students. They are all students, just like Bert, and they share similar characteristics as far as students numbers and Western High.

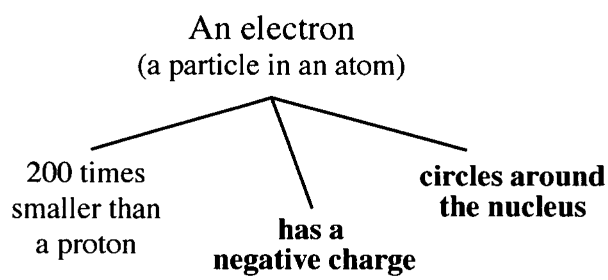
**Figure 7.2: Characteristics of Bert**




In the scientific definition and taxonomy, however, the interlocking definitions may be more difficult to sort out. In the discourse example above, three characteristics were offered to help define electrons:

They have a negative charge.
They circle around the nucleus.
They are two thousand times smaller than protons.

**Figure 7.3: Characteristics of an electron**




The taxonomy which is constructed is smaller than that built for Bert, as Figure 7.3 shows, but neither the terms nor the characteristics contain straightforward, common-sense ideas. Instead they are all locked to other scientific concepts such as *nucleus, proton,* and *charge.* The teacher also offered various acceptable class words for the definition, such as *particles* and *part of an atom.* In other words, all of the terms which make up the definition are science terms which students may need to define or understand before they can use them to define electrons. It is not clear from the definitions whether the students understand the concept of negative charge, or nucleus, or particle. Fred's response that an electron is two thousand times smaller than a proton suggests that students would need to be familiar with the notion of proton in order to understand its relationship to an electron. In fact, the students' task in this lesson was to provide definitions for *electron, proton, neutron,* and *nucleus,* and the resulting acceptable definitions—definitions which the working groups put on the blackboard and which they had corrected for grammatical accuracy using Ms. Armstrong's questions—all contained interlocking definitions:

> Protons are positively charged particles which are found in the nucleus.
> Neutrons are very small particles that have no electrical charge and which are found in the nucleus.
> An electron is a part of an atom which circles around the nucleus and has a negative charge.
> A nucleus is the center of an atom which contains protons and neutrons.

By constructing both everyday taxonomies and scientific ones, Ms. Armstrong illustrated how the parts of the definitions relate to each other by defining common-sense terms using common-sense interlocking terms, and by defining scientific terms using scientific interlocking terms.

Ms. Armstrong used a similar strategy of relating common-sense situations to scientific ones by using analogies to make the science concepts more congruent to the students. For example, she related attraction to lovers, using physical actions to reinforce the idea:

> Teacher: So attract means?... They want to be together. Right? Like lovers.
> Male: Yeah.
> Teacher: Who can I pick on? Tony? When the lovers attract. *(Some laughter as she heads over to Tony with her arms wide. Tony ducks.)* Oh-oh. Oh-oh. Maybe there isn't a minus over there. *(Laughter.)*

She then directly related the scientific term *attract* to the everyday *pull together* using a relational process to translate the two:

> Teacher: Okay positive and negative attract each other. That means that they pull together. Uh two minus charges repel each other. Two positive charges repel each other. So they try to get away from each other.

| attract | means | pull together |
|---|---|---|
| token | rel:int | value |

| | | |
|---|---|---|
| repel | means | try to get away from each other |
| token | rel:int | value |

Later, when Ms. Armstrong asked why electrons did not fly off into space, the question which had prompted the earlier discussion of attraction and the lover analogy, the non-scientific response was the first to be offered:

| | |
|---|---|
| Teacher: | Why do the electrons not fly off into space? |
| Male: | Because they love each other. |
| Teacher: | They love each other. *(Laughter.)* Just like me and you. *(More laughter and feigned horror.)* |

Ms. Armstrong then probed for the charges on the protons and the electrons and asked about the relationship between them:

| | |
|---|---|
| Teacher: | And what do we know about positive and negative? |
| Male 1: | They stay together. |
| Male 2: | They join together. |

She typically kept the everyday analogy comical and involved the students and their lives. Atomic bonding was described as "a marriage made in heaven," protons and neutrons in the nucleus were compared to apples and oranges in a basket, and the concept of the full outer shell in bonding was explained in terms of the number of cars each of two students had in their garages. When introducing the periodic table, much time was spent discussing the layout of a calendar and the activities which students regularly did on certain days so that the students would better understand the concepts of periods and families. All these analogies were teacher initiated, with many questions asked to ascertain that the analogies were being understood by the students, or at least those students who were responding to the questions.

On occasion, Ms. Armstrong also attempted to have students break down the meanings of words before they wrote definitions by considering their parts. In a quick interaction, she related the word *neutron* to *neutral* and asked what the meaning of that term was. In a longer interaction on electronic configuration, she elicited the students' understanding of the word *arrangement* in the phrase *the arrangement of the electrons,* and continued by having the students break down the phrase *electronic configuration:*

| | |
|---|---|
| Teacher: | Okay so an arrangement just means how you have things organized. Okay? Where they are. How they're put together. All right? So. Electronic configuration. Do you see a word in here that can remind |

| | |
|---|---|
| | you what electronic configuration means? Do you see a word in this word? A shorter word? Kim? Kim? |
| Kim: | Some word? |
| Male: | Figure. |
| Teacher: | Figure. Exactly. What does figure mean? |
| Male: | You have a picture of something. |
| Teacher: | A picture. Exactly. Good work. So a figure means a picture... right? So if you think about it electronic... picture... right? Electronic means? |
| Fred: | Uh part of a... oh oh oh! |
| Teacher: | Okay the I-C makes it an adjective. A picture of what? |
| Tony: | The electron. |
| Teacher: | The picture of the electrons. Okay. So it's a big long word. I don't want you to be scared of it... when you see this word think of figure... see the word figure. Figure means picture... electronic okay? Means... a picture of the electrons. So that's all it means. It means... how many electrons are in each shell. Okay? |

The students later constructed the written definitions for these terms, which they studied for their tests and for the review sessions.

Questions which probed the students' background experience and knowledge outside of the ESL science content which Ms. Armstrong presented were rare, and therefore teacher recasts of students' common-sense answers were also uncommon. Most often, Ms. Armstrong responded to the students' answers by repeating what the student had said, by accepting the response with no repetition or comment, or by evaluating the students and/or their responses. Like the correction of the students' written work on the board, most of the recasts focused on form. Sometimes they were solely concerned with pronunciation issues where the teacher repeated the word correctly and instructed the student or all students to repeat, turning the interaction into a quick pronunciation drill:

| | |
|---|---|
| Rhonda: | The nucleus.* *(*mispronounced)* |
| Teacher: | The nu cle us. Everybody? Nucleus. |
| Students: | Nucleus. |
| Teacher: | Nucleus. |
| Students: | Nucleus. |
| Teacher: | Again? |
| Students: | Nucleus. |
| Teacher: | Good. |

The aim in this type of recast was to encourage the students to pay more attention to this word and its pronunciation difficulties.

There were times where the teacher's recast offered a correct grammatical form to replace the student's incorrect one, as in the following example:

| | |
|---|---|
| Male: | Who is teached by Ms. Armstrong. |
| Teacher: | Who is taught by Ms. Armstrong. |

In these cases, the recast was a straightforward substitution of the correct form (e.g., *taught)* for a form which was grammatically unacceptable in standard English (e.g., *teached).* Grammatical recasts were also provided in cases where plurality was the issue:

| | |
|---|---|
| Teacher: | What do you know about family eighteen? |
| Fred/Ken: | They're all gas. |
| Teacher: | They're all gases. Right. |

There were also examples where the students had the correct idea, but offered their response in the form of an adjective instead of the nominalized form which was required. In the following exchange, the teacher is talking about conductivity:

| | |
|---|---|
| Teacher: | What kind of energy? |
| Males: | Hot. |
| Teacher: | Heat. Okay. So in other words metals will conduct or send out heat. Okay? *(She discusses cooking in metal pots, then continues.)* So they're good conductors of heat and also good conductors of? What else will they conduct? What else will they… will they allow to move through them besides heat? |
| Tony: | … Electric. |
| Teacher: | Electricity. |
| Tony: | Uh electricity. |

The teacher recast "hot" to "heat" and "electric" "to electricity." The first was not a correction of form, as "hot energy" is grammatically acceptable. Instead, it is a functional recast, a move towards a more scientific meaning from a *quality* to a *nominalization,* reflecting Halliday's general drift of grammatical metaphor (Halliday, 1998). The second move, from "electric" to "electricity" also reflected this shift, although the teacher's question in this example required a nominal form and therefore could arguably be called a recast of form.

Occasionally there were other recasts which involved making changes to the grammar of the response to make the utterance more acceptable in the context. In the following example, the teacher had been asking questions about the families and periods in the periodic table. She established that periods all have the same number of electron shells and asked what else the students know:

| | |
|---|---|
| Teacher: | What else do we know? |
| Tony: | They have seven periods. |
| Teacher: | There are seven periods. Good. Okay yes. There are seven periods. What do you know about one of the periods? |

Tony responded using a relational process which might have been appropriate had he specified that "they" referred to periodic tables, but as it stood, the discourse had not set up this interpretation. Instead, an existential process was needed, which was what Ms. Armstrong provided in her recast. In fact, explicit reference for pronominal participants was often at the core of the utterances which the teacher recast in this way. In the following exchange, the teacher was introducing the idea of conductivity by asking why food is not cooked in wooden pans:

| | |
|---|---|
| Teacher: | Why don't you put your food in a wooden pan? |
| Male: | It burns. |
| Tony: | It will get burned. |
| Teacher: | Yeah. The wood will burn. But what about metal? |

Both students' responses involved the pronominal participant *it,* which grammatically may relate to the food, but to construct meaning correctly in this context the *it* needs to be related only to the wooden pan. The teacher's recast clarified the participant, bringing *wood* to the foreground to be contrasted with *metal.*

Another example in which the recast attempted to improve the student's response by changing the lexicogrammar involved an utterance which appeared frequently in the students' interviews and will be brought up again in the next section. In trying to identify the physical properties of nonmetals, Tony offered the following quality:

| | |
|---|---|
| Tony: | They are easy to break. |
| Teacher: | Yes. They're brittle. So if you bend them they break. |

Rather than altering the grammar to improve Tony's utterance, Ms. Armstrong offered a vocabulary item which captured Tony's meaning, then rephrased his sentence as a causal conditional. In other words, her recast offered both a new lexical item and a different grammatical construction, thereby moving from a focus-on-form recast to a more functional one.

Some of Ms. Armstrong's recasts involved grammatical metaphor, particularly nominalization. For example, in reviewing the procedure for the first lab of the unit, she reviewed what the students needed to do:

| | |
|---|---|
| Teacher: | Okay then what? |
| Students: | Then use the ruler. |
| Teacher: | And? |
| Students: | How... how high. |
| Male: | Measure how high the water is. |
| Teacher: | And measure the height of the water. |

Her recast changed the student's clause, "how high the water is," to the nominalized form, "the height of the water," offering a more metaphorical construction. Yet she not only moved from clause to noun, there were times when she also moved in the opposite direction:

| | |
|---|---|
| Teacher: | What does mass mean? |
| Fred: | ... Weight. |
| Teacher: | It means how much it weighs. Okay. It does on earth but actually mass means the amount of? |

The teacher also moved between the two forms when she felt it would help the students understand, even when she was not recasting a student's response:

| | |
|---|---|
| Teacher: | And this is going to be the width of the band... So in other words how wide is it going to be. |

Consistent with her goals to simplify language, it was less common for Ms. Armstrong to move into a more grammatically metaphorical construction than it was to go in the opposite direction; when a metaphorical construction occurred in the textbook or in the oral discourse of the classroom, she typically offered the more congruent form to help the students understand.

### 7.2.2 Prompting logical reasoning

In the previous section, it was mentioned that Ms. Armstrong often introduced new content by reading aloud from the textbook or from worksheets she distributed. She would have students in turn read a short section, or she would read the section herself, and then ask students questions which targeted the information contained in that section. Sometimes the questions required students to repeat what was written in the text; these often revolved around defining or describing terms:

| | |
|---|---|
| Teacher: | *(Reading from handout.)* Every other sort of atom has a different number of protons. The number of protons in an atom is therefore an important number. It is given a special name. It is called the atomic number. *(She then addresses the students.)* Okay? Now this is very easy… however I find that students tend to forget. I really want this to be in your memory. Locked in. Okay? Atomic number means number of? |

But on many occasions, Ms. Armstrong involved causal discourse in an effort to prompt logical reasoning:

| | |
|---|---|
| Teacher: | Okay Tony. Would you continue: |
| Tony: | *(Reading.)* The electrons are held in place around the nucleus like a satellite in orbit around the earth. Each proton plus holds an electron minus in its orbit. For every proton plus in the nucleus there is one electron minus circling the nucleus. |
| Teacher: | Okay. So for each proton there is… an electron. Okay? So if there's one proton how many electrons would there be? |
| Fred: | … One. |
| Teacher: | Say it again Fred? If there is one proton? |
| Fred: | One. |
| Teacher: | How many electrons are there? |
| Males: | One. |
| Teacher: | If there are three protons? |
| Male: | Three. |
| Teacher: | How many electrons are there? |
| Students: | Three. |
| Teacher: | If there are five protons how many electrons are there? |
| Students: | Five. |
| Teacher: | Right. Okay there has to be the same number of plus charges… as minus charges. So if there are six electrons how many protons are there Rhonda? |
| Rhonda: | … Six. |
| Teacher: | She is awake. Okay. Good enough. |

Rather than focusing on the students' ability to define terms, this type of questioning checked the students' comprehension of the information in the reading passage by using a causal *if... then...* relation to apply the information presented.

Ms. Armstrong prompted logical reasoning by asking questions which attempted to probe the text more deeply. For example, after reading a sentence on the balance of charges, she probed students' understanding:

Teacher: *(Reading from text.)* Balance of charges.... We know that protons and electrons have different charges but what about the atom itself? *(To the students.)* What about the atom itself?
Male: No charge.
Teacher: Why not?
Ron: Because they both like... minus... minus in the middle? I don't know. Guess.
Teacher: Well let's not guess. Let's take a look at this. *(Looks at the chart in the book, which lists five elements and their numbers of protons.)* All right. Lead has how many protons?
Male: Eighty-two.
Teacher: Eighty-two. How many electrons?
Students: Eighty-two.
Teacher: So if there are eighty-two protons how many plus charges are there?
Male: Eighty-two.
Teacher: Okay. How many... minus charges are there?
Male: Eighty-two.
Teacher: Eighty-two.. Plus eighty-two... minus eighty-two equals?
Students: Zero.
Teacher: Zero. Does the atom have an overall charge?
Students: No.

Through these questions, she prompted students to explain why the atom has no charge, thereby promoting logical reasoning.

Questions which required students to use their background knowledge—information that was not acquired directly from the ESL science classes—were rare. Most of these were constructed as *why*-questions by the teacher and were related to the topic at hand:

Teacher: Why don't they measure... protons and neutrons in grams?
Male: Because... they're smaller...
Teacher: If we put an atom one atom on a scale. If you put one atom on your bathroom scale could you measure it?

| | |
|---|---|
| Male: | No. |
| Teacher: | Why not? |
| Male: | Too small. |

Other than asking about students' daily routines in order to construct an everyday taxonomy to contrast with families in the periodic table, questions which asked for the students' own experiences were rare, but they offered an excellent opportunity for the students to construct explanations and for the teacher to work with those explanations. On one occasion, for example, when the students were discussing how to separate certain mixtures, the teacher asked if anyone had ever panned for gold. One student had and was asked to explain the procedure:

| | |
|---|---|
| Fred: | Uh first |
| Teacher: | Okay listen?... Yeah go ahead. |
| Fred: | Put the sand and water into the bowl? |
| Teacher: | In a bowl? In a pan? |
| Fred: | Yeah and then and then I... sort of like uh |
| Teacher: | Shake it? |
| Fred: | Shake it and then the... the sand would be on the top and the gold would be... on the bottom. |
| Teacher: | Oh so the gold will fall down to the bottom because the gold is heavier. Right? |
| Fred: | Yes. |

Fred's explanation began as a set of instructions, "put the sand and water into the bowl," then continued as a potential recount, "Yeah and then I" which the teacher attempted to bring back to an instruction by offering a material process in what could be understood to be the imperative form, "shake it." Fred finished by suggesting a conditional outcome of such an action, which Ms. Armstrong recast in a more general reflection containing the reason. She then looked for a picture which would help illustrate the procedure, and failing to find one, offered a recast of Fred's explanation again for the class:

| | |
|---|---|
| Teacher: | Sorry. All right. I'll have to look for it. I'm not quite sure where that book is but anyway you've got this big pan and you've got— you have to put water in it... okay? So you put in the sand and the gold in the pan with the water. You slosh it around. The gold will fall to the bottom. |

In this recast, she stated the equipment needed, what had to be done, and what would occur, using the genre of giving instructions rather than mixing genres as Fred had done.

The two labs which Ms. Armstrong's class carried out involved doing a review of definitions, but focused on the use of discourse which is characteristic of sequencing and logical reasoning (i.e., causal discourse). These labs exhibited a four-step process. The second lab, "The Chromatography Lab," will be used to illustrate this process. In step one, Mrs. Armstrong introduced the lab by stating that in the next class the students would be "doing an experiment on chromatography," and then asking the students what Olympic athletes are tested for and if anyone knows how this testing is done. After eliciting various incorrect answers, she acknowledged a correct response—that "a piece of paper is put in the urine"—and again related this back to the upcoming lab. The questions characteristic of the first step in this lab involved asking the students what they already knew, but typically when she began an activity, she reviewed what had been taught earlier. In all cases, the language the teacher aimed for was generic rather than specific.

In the introduction to the chromatography lab, sequential explanations played a key role:

| | |
|---|---|
| Teacher: | How can they find out? How can they know? [if an athlete uses drugs] |
| Male: | By test like... they test your... pee in some way. |
| Teacher: | Okay. The polite word for pee is urine. |
| Male: | Okay. |
| Teacher: | So they test your urine. And how do they test it? What do they do? How can they find out from your urine? |
| Rick: | They put something in an then then... something showed up. It's different than— |
| Teacher: | And what do they do? |
| Rick: | And then they know. |
| Teacher: | Yeah but what do they do? |
| Male: | They use centrifuge. |

The students continued offering potential sequences of action which the teacher then connected to what they were going to do in the lab. In other words, she co-constructed a generalization or theory which related to the lab and then held up the experiment as a way to illustrate or provide evidence for the generalization or theory. The generalization she arrived at by the end of this introduction was that "scientists can find out if there are chemicals in food or if there are drugs in urine by using chromatography." The purpose of this lab, Ms. Armstrong stated, was to use chromatography paper to show that some colors are mixtures and some are not.

In the second step, the teacher described what the students were going to do, using the lab report format as the basis of her instructions and questions. She showed the students the equipment they would be using, supplying the labels as they fit in the procedural discourse she was using or using the language of description ("this is chromatography paper"). Her procedures also included making sure the students remembered where to put their names on the lab reports and how to present the finished document. The step two language was clearly procedural, but she projected the action into the future using verbal groups such as "we're going to be using," "you're going to be putting," and "you're going to have to be."

The third step of the lab process was carrying out the experiment, and as mentioned earlier, the students typically used their first languages during their group work unless the teacher or researcher asked specific questions such as "what are we watching for," which requested the students' reflection on their actions, or when the teacher was giving suggestions or comments on the students' work as in the following example:

| | |
|---|---|
| Teacher: | Oh oh. Okay let's throw that one out. That's not a bad dot. It's a little big but it'll work. Okay great. Oh it's a perfect green dot. You're lucky. |

The latter types of comments were not usually responded to by the students, and no similar action discourse was uttered by the students in English.

The final step began with a co-constructed recount of the lab, used to make sure the sections of the lab report on observations and findings were complete. This language typically involved the teacher asking questions primarily to elicit a recount of what the students had done, but also reminding them of the parts of the lab report format and asking for definitions of these parts. The excerpt below illustrates this:

| | |
|---|---|
| Teacher: | What does material mean? |
| Male: | What do we use. |
| Teacher: | What did we use. And what did we use? |
| Male: | Three large test tubes. |

Rhonda: Chromatography paper.

*(Several turns later.)*

Teacher: What's after procedures?

Males: Observations.

Teacher: Observations. Good. What does observation mean?

Male: What you saw.

Teacher: What you saw. Exactly. And what did we see?

Rick: See the color... changed.

Teacher: Okay we saw the colors—

Rick: Spread out.

Teacher: change but... before we saw the color change what did we see happen?... Before the colors changed? What happened right at the beginning?

Rick: The colors spread out.

Teacher: Well before they spread out.

Male: They climb up.

Teacher: Yeah. They climbed up or they moved up. Right? The colors moved up. So the colors started to move up the chromatography strips and they started to...

Male: Spread out.

Teacher: Spread out and... change colors. Exactly. Okay.

The teacher also helped the students construct their conclusion to the lab during this fourth step. She first asked what the conclusion responded to ("the purpose") and asked again what the purpose was. The students moved out of the past tense recount to respond to this question in the same way it had originally been posed: "To find out which colors are pure colors and which colors are mixtures." Ms. Armstrong then asked questions to find out which colors were pure and which were mixtures, and how the students were able to figure this out:

Fred: Because purple and green separated.

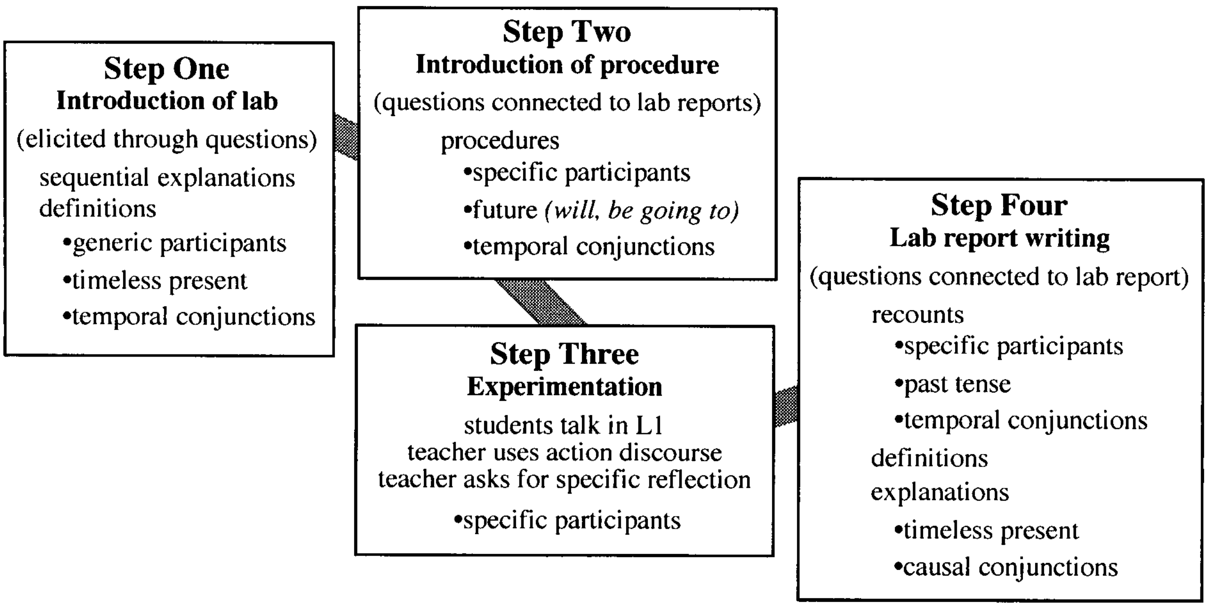
Through her questions, she reinforced the idea that what the students had done in their experiment (the specific) led to the more generalized findings about the colors. This was further reinforced by four questions which she asked the students to answer as part of their lab report, but which were asked orally first:

1) What are the components of green food coloring?
2) What can you conclude about the purple dye?

3) What might happen if ink rather than pencil were used to mark the line on the chromatography paper?
4) Why should green food coloring be classified as a mixture whereas yellow, blue, or red should not?

The questions focused primarily on classification and causal relations (principles), requiring the students to think in general terms rather than the specific language of their experiments. The steps that the teacher generally followed for the two labs, with the types of language each step involved, is captured in Figure 7.4.

**Figure 7.4: The four steps of the lab and accompanying language features**



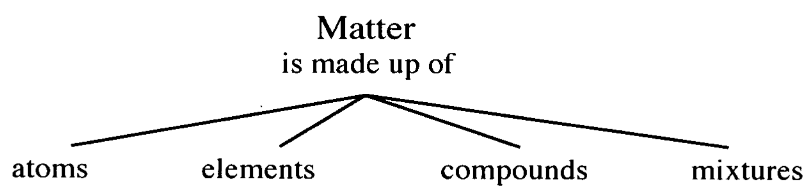

In general, the science language and knowledge that was constructed in English in the ESL science class was done primarily through interactions between the teacher and her students. These interactions were controlled by the teacher, who introduced both the language and the content and questioned the students to ensure they had understood what she had introduced. The majority of the questions related directly to the content that had been presented earlier in the unit, creating a sense in the data that the students' knowledge of chemistry began with what they were studying in this ESL science class. Unlike the situation in Mr. Peterson's mainstream science class, few questions related to the students' prior or non-science experiences and knowledge.

The questioning technique which Ms. Armstrong commonly used allowed her to check the students' comprehension of the content easily, but it appears from the data that it did not offer many opportunities to the students for extended discourse. Yet as noted at the beginning of this section, when time was given for extended discourse, such as the many problem-solving sessions, the students opted to use their first languages, limiting their chances to practice and develop their oral English skills in constructing science language. They could fill in the blanks in written tests and respond easily in short answers, but they often struggled with longer, novel utterances as the next section will show.

### 7.3 Tracking the construction of three key concepts

Section 7.1 included a diagram which Ms. Armstrong had presented to the students and which she had followed to maintain a logical flow for the concepts she was presenting. The textbook constructed a taxonomy of matter which fit Ms. Armstrong's teaching flow by suggesting the same taxonomic relation of "X is made of Y." In the teacher's chart (Figure 7.1), matter is made up of all the concepts marked in upper case bold face which occur under it, or in other words, atoms, elements, compounds, and mixtures. The textbook also stated that matter was made up of these four "things," creating the taxonomy pictured in Figure 7.5.

**Figure 7.5: The taxonomy of matter taught in Ms. Armstrong's class**




Early in the unit, the students created definitions for six terms from the diagram *(chemistry, matter, atoms, elements, compounds,* and *mixtures),* and the teacher focused on each topic area, including forms of matter and the periodic table, as she progressed through the unit, whenever possible using knowledge which had been constructed earlier to help present the later topics.

Section 7.2 described how Ms. Armstrong attempted to build technicality and prompt logical reasoning through her teacher-led lessons and the activities she provided for the students. It was pointed out in the first section of this chapter that Ms. Armstrong had students create their own "chemistry dictionaries" which contained definitions of key terms which students had worked out in groups and had put on the blackboard for grammatical correction. These definitions followed a particular structure which Ms. Armstrong frequently reinforced. The writing and drilling of definitions were her most common ways of helping her ESL students build technicality. Moreover, because the students typically used their first languages when they had the opportunity, the teacher's questioning was the primary method for both building technicality and promoting logical reasoning in English.

To examine Ms. Armstrong's methods more thoroughly, the following sections will probe how she attempted to construct meaning for the same three key concepts as Mr. Peterson did in his unit: *physical properties, compounds,* and *mixtures.*

### 7.3.1 Building up an understanding of *physical properties*

Figure 7.5 above shows that compounds and mixtures were primary topics in Ms. Armstrong's overall unit plan, but as Mr. Peterson had noted with his students, physical properties play an important role in the study of chemistry. In fact, the textbook which Ms. Armstrong used with her students stated that "atoms, elements, compounds, and mixtures are studied by learning about their properties" (Scott, 1987, p. 19). So what did Ms. Armstrong teach her students about these properties? And when and how did she do this?

As section 7.2 described, Ms. Armstrong often used oral reading from the textbook along with frequent oral drills to reinforce the concepts she was attempting to teach. With the topic of properties—or characteristics—she also set up taxonomies of everyday ideas to help the students understand. Moreover, she used the topic to review how to write definitions and to help the students improve their note-taking skills. There was one observation activity which required students to describe items using physical properties, and a video helped illustrate the property *reactive* in certain families of the periodic table. The teaching methods which Ms. Armstrong used helped to construct particular knowledge about physical properties, as will be discussed in this section.

Figure 7.1 shows that early in the unit, Ms. Armstrong introduced the topic of matter, presenting it through its three states: solid, liquid, and gas. On January 15th, she discussed and asked questions about the shape, temperature, volume, and description of the three states along with examples of each. The students completed a chart of matter, as shown in Figure 7.6. On February 5th, they did an experiment to show that air has volume and is therefore matter. Although most of one 90-minute class was spent on the chart activity and more than one class was spent on the lab, no mention was made that shape, temperature, and volume could be considered physical properties of matter.

**Figure 7.6: The three states of matter**

**STATES OF MATTER**

| | **Shape** | **Temperature** | **Volume** | **Description** | **Examples** |
|---|---|---|---|---|---|
| **Solids** | does not change | coldest | does not change | holds size and shape can hold in hand | iron, steel, rice, ice, frozen juice |
| **Liquids** | can change takes shape of its container | between solid and gas | does not change | wet and runny | water, ocean, Coke, juice, rain |
| **Gases** | can change takes shape of its container | hottest | fills the container spreads out | can't see or touch can't hold it | air, oxygen, nitrogen, carbon dioxide |

It was not until Ms. Armstrong began talking about atoms on February 13th that the term properties was introduced:

| | |
|---|---|
| Teacher: | Has anybody ever seen an atom? |
| Male 1: | No. |
| Students: | No. |
| Teacher: | Not yet.... So how do they know what it looks like? |
| Male 1: | Imagination. |
| Male 2: | Guess. |
| Male 3: | Make it up. |
| Teacher: | That's right. Imagination or a guess. Now they've... guessed because they have figured out some properties... of atoms. What's a property? |

| | |
|---|---|
| Ron: | Like how (xx) |
| Teacher: | Like how hmm hmm. *(She couldn't hear him.)* |
| Ron: | How the atom works. |
| Teacher: | Yeah okay. Yes. So how it works would be a property. So a property is the same as... characteristics. Okay? |

In this short discussion, several relations concerning the concepts of properties were constructed. The first was causal:

| | | |
|---|---|---|
| The scientists have guessed (what an atom looks like) | because | they have figured out some properties |

In other words, knowing about the properties has led the scientists to their guesses. But whereas this causal relation can tell the students a little about properties, it does not offer them a definition of the term. Ms. Armstrong therefore asked for a definition, and Ron responded with a construction which fit into the same type of causal relation as the teacher's:

| | | |
|---|---|---|
| The scientists have guessed (what an atom looks like) | because | they have figured out how the atom works |

It is unclear from the interaction, however, whether Ron was constructing a token/value relation, which is typical of a definition as it identifies the term or equates it with another term, or if he was intending a carrier/attribute meaning. In other words, was he suggesting that the term *property* means how an atom works, or was he offering an example of a property? Ms. Armstrong's response suggested that she interpreted his meaning to be one of carrier/attribute: There are many types of properties, and "how it works" is one type.

The final relation Ms. Armstrong offered in this short dialogue was the token/value relation *X is the same as Y.* She equated *properties,* the new term, with *characteristics,* a term which the students had come across on earlier occasions as they practiced writing definitions. The teacher had introduced the idea of characteristics earlier in the school year as she taught students to create definitions by stating the term to be defined, its general class word, and its specific characteristics, as discussed in Section 7.3.1. In the discussion of properties above, she presented a token/value relation:

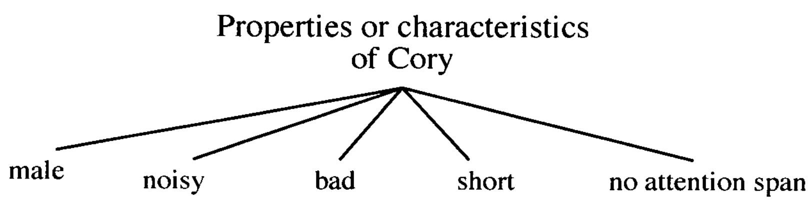
| | | |
|---|---|---|
| a property | is the same as | characteristics |
| token | rel:int | value |

She continued by asking for the characteristics—or properties—of a student who regularly misbehaved in class:

| | |
|---|---|
| Teacher: | So what's one characteristic of Cory? He's? |
| Male: | A male. |
| Teacher: | Male. And he's? |
| Students: | Noisy. |
| Teacher: | Noisy. And he's? |
| Male: | Bad. |
| Teacher: | Bad. Okay. So those are the— |
| Student: | Terrible! And he's not tall. |
| Teacher: | And he's short. And he doesn't have much of an attention span. *(Laughter and agreement.)* Right? Okay. So those are the characteristics or properties... |
| Students: | Yeah. |
| Teacher: | The rest of my students are the same. All bad. Noisy. No attention span. |

The taxonomy which Ms. Armstrong built up as a comparison to the scientific taxonomy to explore the meaning of *properties* or *characteristics* during this initial and everyday definition of the term is not complex; it contains only one layer of detail, as Figure 7.7 shows (see also Section 7.2.1, Figure 7.2).

**Figure 7.7: Model taxonomy of "everyday" properties**

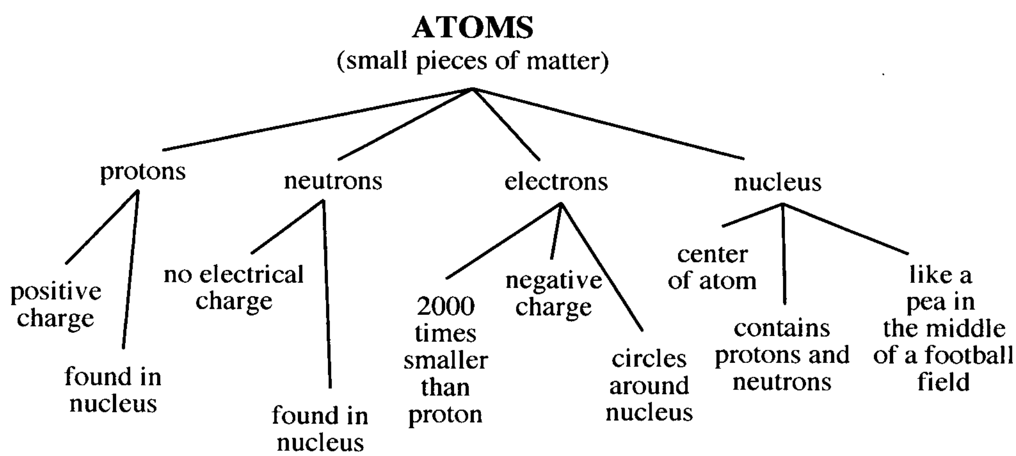



Approximately two weeks later, Ms. Armstrong involved the students in another discussion about characteristics as she reviewed again how to write definitions:

| | |
|---|---|
| Teacher: | What are characteristics? |
| Males: | How to describe it. |
| Teacher: | How you describe it. Excellent. |

She then continued by asking students to define one of their classmates, Bert, as they had done with Cory earlier. The students responded by suggesting various characteristics, as they had done earlier, but these were rejected as Ms. Armstrong searched for the one characteristic which would make this students distinct from all others. After finishing, she repeated this activity by asking for a definition of an overhead pen, and once again the students offered various characteristics of overhead pens, all of which were rejected because they did not distinguish the item from all other similar ones. Finally, she directed the students to write definitions for *electron, proton, neutron,* and *nucleus* (see Section 7.2.1). Based on the "special characteristics" which the students offered for these four terms, the taxonomy in Figure 7.8 was created.

**Figure 7.8: Description of the atom**




What Ms. Armstrong did was equate *properties* with *characteristics* and then focus on "special characteristics" which she stated are used to distinguish one item (or student) from another when writing definitions. At an explicit level, therefore, she taught the students that items (or students) have various properties, but only certain properties help distinguish one item (or student) from another. Moreover, she reinforced the idea that properties can be subjective, thought up as needed to describe an item or person. She illustrated this using both everyday items (pens, students, etc.) and terms in science (electrons, protons, protozoa, etc.). But as of the end of February, what Ms. Armstrong had not done was encourage the students to consider what the scientific physical properties were. In other words, the teacher had not built up a taxonomy of scientific properties at a general level; instead, each new item or group of items she presented was connected to a specific—and frequently subjective—taxonomy limited to only the properties (or single property) which would help define it.

In March, Ms. Armstrong introduced the periodic table of the elements, comparing it to a calendar and showing how each period or family contains elements which have similar characteristics. She did this by asking students what all Mondays have in common ("school," "Ron has a tutor," "Kim has a tutor"), what Saturdays have in common ("we can sleep until twelve o'clock," "Keifer goes to Japanese school"), and what each week has in common with every other week ("They've got seven days"). She then compared the families on the periodic table with the everyday concept of families:

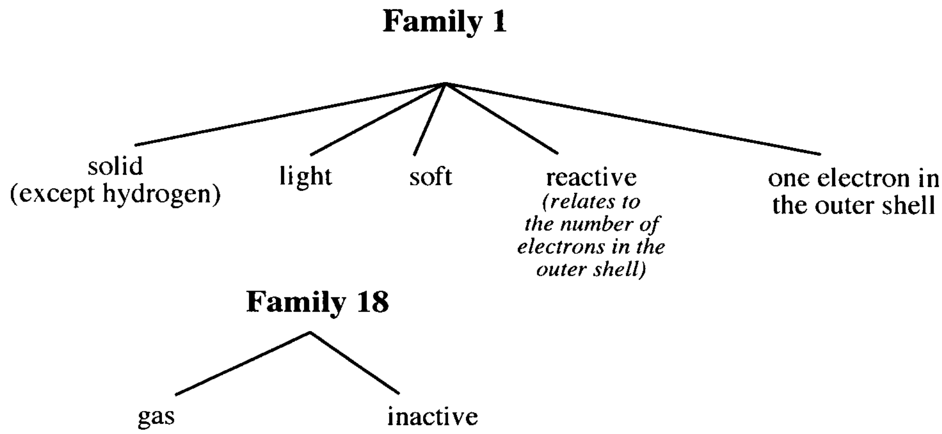
| | |
|---|---|
| Teacher: | In your family then you probably have similar characteristics to your brothers and your sisters. Right? You have some similar characteristics but some characteristics are different. Kathy you're not identical to your sister right? You have some characteristics that are different? But you're very similar. Okay? All the members of this family have similar characteristics but they're not exactly the same. All the members of this family have similar characteristics but they're not exactly the same. Okay? |

Having set up this comparison and directed the students to copy notes which also made this claim from the overhead projector, Ms. Armstrong asked over the next few classes about the similarities in both everyday families ("All the boys might be quite tall? Maybe they have big ears? A big nose?") and families in the periodic table, frequently using family one to convey the latter concept:

| | |
|---|---|
| Teacher: | What do we know about this family then? |
| Fred: | All metal. |
| Teacher: | Yes. And what's a characteristic of those metals? They are all light metals. They are all soft metals. Okay? And they are all very active metals. |

In fact, Ms. Armstrong created taxonomies for both family one and family eighteen and used these repeatedly as her examples of similar characteristics. The two taxonomies, shown in Figure 7.9, were not deep and, similar to her earlier constructions, they offered characteristics specific to the term or group. No general taxonomy showing types of properties had yet been constructed. Note that both physical and chemical properties were included in the teacher's taxonomy.

**Figure 7.9: Taxonomies offered for Family One and Family Eighteen**

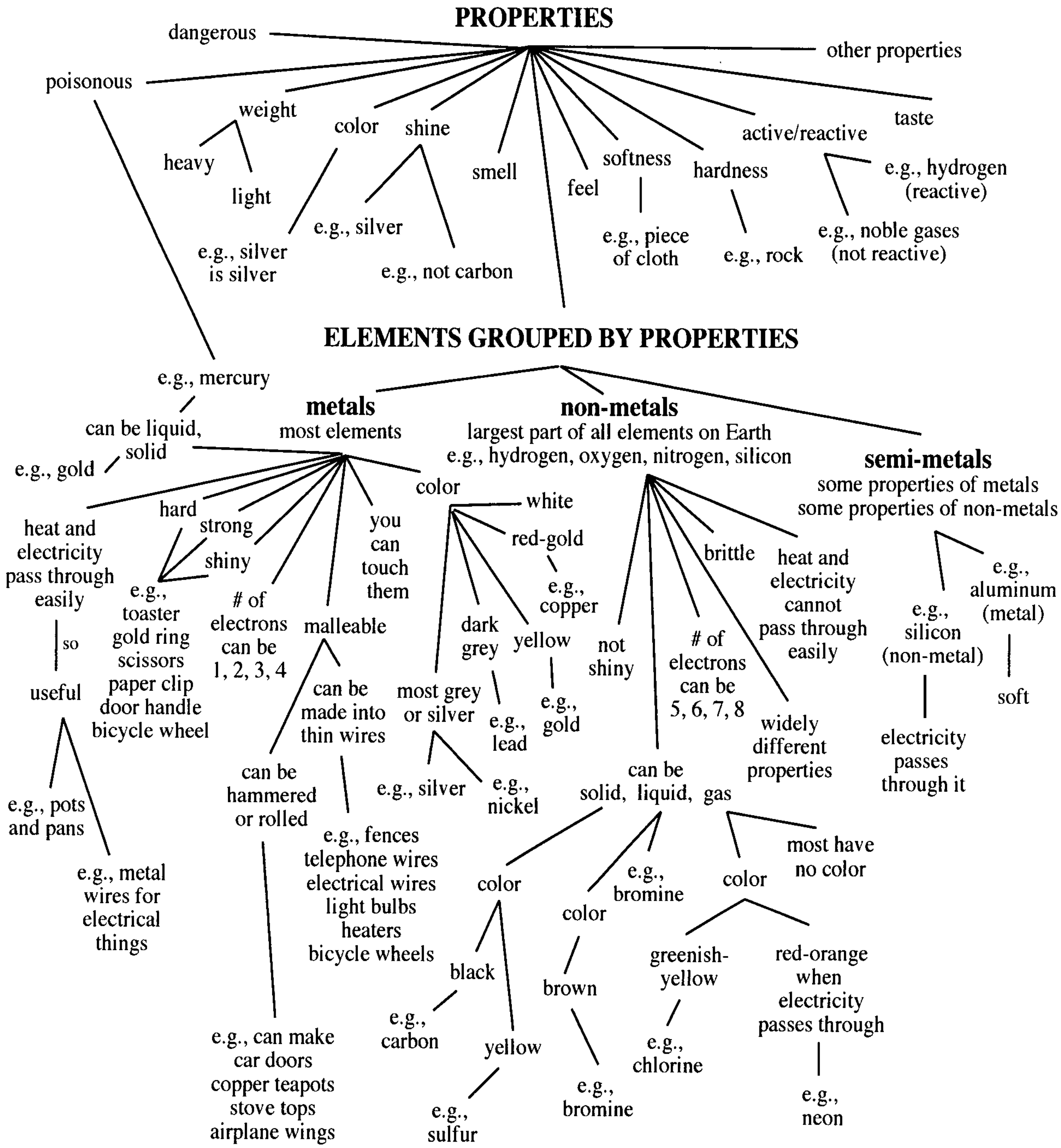



In April, Ms. Armstrong had the students take notes from the textbook's description of properties. At this time, the book's definition was presented as a token/value relation:

| | | |
|---|---|---|
| Properties | are | the things we learn by seeing, feeling, smelling, and watching something. |
| token | rel:int | value |

There is an issue which arises here but which was not addressed by Ms. Armstrong. The definition in the text did not specify physical or chemical properties, yet as shown in Figure 7.10, the teacher brought in examples of chemical properties, such as the number of electrons in the outer shell of an atom. Earlier in the unit, she had stated that atoms could not be seen, so how could the number of electrons in the outer shell of an atom be a property, based on the definition given in the textbook? Ms. Armstrong had divided properties into physical and chemical, but except for eliciting an example of each part way through this section of the unit (physical properties, e.g., size; chemical properties, e.g., one electron in the outer shell), no explicit taxonomy of properties had been constructed in class. Moreover, what the textbook offered, which was read aloud paragraph by paragraph by the students and the teacher with occasional drilling of the material, was limited in its scope as well. In the three-paragraph section headed by *Properties,* the term was defined, the concept heralded as the way through which atoms, elements, compounds, and mixtures are studied, and four examples of properties listed: color, shine, softness, and hardness. The text then stated that the elements on the periodic table "are known and grouped by their properties" with metals

**Figure 7.10: A web of properties created by the various discourses**




and non-metals offered as the two main groups and semi-metals as a group which falls in between. Further information was given about these groups over the next three pages; the web which can be created from this textbook discussion, as well as from other areas of the text which surfaced in the discussions of mixtures and compounds and other information which Ms. Armstrong brought up in class, is captured in Figure 7.10. It has been labeled a web rather than a taxonomy because it contains more than one taxonomy.

The web of concepts which was constructed through the various discourses and presented in Figure 7.10 does not in fact offer properties which distinguish the groups. The text states that conductivity is the "main property of a metal" and that "heat and electricity do not pass through non-metals easily. Other than that, the non-metals have widely different properties" (Scott, 1987, p. 20). Yet according to the text, semi-metals have properties of both metals and non-metals. The text does not present a list of properties, so it is not clear how the properties can distinguish these three groups. In other words, the text claims that the elements are grouped by their properties, yet it does not present a sufficient enough taxonomy of properties to suggest how this could be so.

Using whatever information about properties and characteristics which had been discussed in Ms. Armstrong's class and whatever background knowledge existed about the topic, the students carried out an observation activity on April 12 in which they were required to describe eighteen common elements (e.g., iron, lead, gold, copper, nitrogen) stored in small glass tubes. They were given a task sheet which was similar to the one in Figure 7.11 and told to disregard the heading *conducts electricity.* At the top of the page, Ms. Armstrong had written some properties as a guide:

State: Solid, liquid, gas.
Shiny? Dull?
Colour?
Weight? Heavy? Light?

**Figure 7.11: The observation and description activity worksheet**

| ELEMENTS | | | |
|---|---|---|---|
| Name | Symbol | Characteristics | Conducts electricity |
| | | | |
| | | | |

Ms. Armstrong also instructed the students orally on these choices, modeling the types of words they should include:

| | |
|---|---|
| Teacher: | I'll let you have a look at this. Okay? So what can you say about hydrogen? |
| Male: | Nothing. |
| Male: | Air. |
| Teacher: | It's not air. It's hydrogen. |
| Keith: | It's clear. |
| Teacher: | Clear? Okay? Yes? What else? |
| Male: | Gas. |
| Male: | Nothing. |
| Teacher: | It's a gas. It's not nothing. It's not nothing. Can you see anything in there? |
| Male: | No. |
| Teacher: | So we could say it's invisible. And it's also light. Right? Very light. If you were to hold this little bottle of hydrogen in your hand… and the little bottle of copper… okay? Copper is definitely heavier. All right?… Okay… So that's what I want you to do. You're going to write the symbol. And then you're going to write some words to describe it. So what kinds of things can you write here? Well you can write the state. Is it a solid. Is it a liquid. Or is it a gas. Is it shiny? Is it dull? What color is it. Weight? Is it heavy or is it light? Now under conducts electricity just leave that blank for now. |

The students carried out this activity speaking almost exclusively in their first languages and limiting their written descriptions to the categories the teacher had written in her instructions and reviewed orally just prior to the activity. The students' limited number of characteristics reflected both the limited taxonomy of properties which had been constructed as well as the activity itself which, except for weight (note that mass was not addressed), could only be seen through the glass tube. Moreover, despite the fact that the elements in the activity were metals and non-metals, the activity did not require the students to group them the way that the taxonomy of the discourse had set up. This may have created somewhat of a mismatch between the theoretical taxonomy and the practical use of it for grouping or defining elements.

Throughout Ms. Armstrong's chemistry unit, properties—or her preferred term *characteristics*—were presented and discussed as they related to specific items or groups, both everyday and scientific, usually as these items or groups needed defining. This led to some confusion about the definition and use of the term *properties* in science. As mentioned earlier, there seemed to be a contradiction between the teacher's statement that atoms cannot be seen, but have been visualized because scientists learned about their *properties,* and the textbook's comment that "properties are what we learn by seeing, feeling, smelling, and watching." Also, *properties* are what groups elements, yet the taxonomy constructed through the various classroom texts seems inadequate to support this claim. *Properties* means *characteristics,* according to Ms. Armstrong, yet Cory had many which were enthusiastically accepted by the teacher while all but Bert's student number and school name were rejected a short while later. Furthermore, the characteristics offered for these two boys were subjective and everyday, and *properties,* as it concerns physical chemistry, is a specific science term which is neither subjective nor everyday. In fact, comparing characteristics to properties is rather like comparing *stick to* to *attract*—they are different concepts which are related to different contexts. Therefore, no clear scientific definition of properties was constructed in Ms. Armstrong's class.

Beyond some basic qualitative properties and an everyday concept of weight (not mass), the students were not offered a concise scientific taxonomy of physical properties which they could consult when they needed to talk about the various elements. The limited qualitative taxonomy which was constructed in class, while satisfying the definition of properties offered to the students by the textbook ("properties are what we learn by seeing, feeling, smelling, and watching something"), was not inclusive enough to help the students distinguish elements based on their physical properties. This had important consequences for Ms. Armstrong's teaching of mixtures, a topic which will be discussed in Section 7.3.3.

### 7.3.2 Building up an understanding of *compounds*

In early January, when Ms. Armstrong introduced the overview of the unit, she read with the students the textbook introduction to matter. On page five, the textbook offered definitions for *atom, element, compound,* and *mixture,* the four "things" which make up matter:

To a scientist...

- the word **compound** means something that is made when two or more elements join. Some compounds you know are water, gas, fats, and salts.

The students were quizzed on the definitions of the four terms in mid-January, then the term *compound* was put to rest until mid-May. At that time and over the period of about a week, the students read aloud from pages 24 to 31 of the textbook, the chapter on compounds, with the teacher carrying out regular review drills of the definitions presented there:

| | |
|---|---|
| Teacher: | And what about a compound then?... |
| Male: | Change properties. |
| Teacher: | Change properties. Yeah. |
| Female: | Change chemically. |
| Teacher: | Chemical changes and... |
| Female: | Can't separate by physical means. |
| Teacher: | Cannot be separated by physical means. Exactly. Okay. But you can change— or you can separate the elements of a compound by chemical means. Okay? It is possible but it's not easy. |

The acceptable definition of compound, which was constructed by the students in groups and put on the blackboard for grammatical and mechanical correction before being copied into their chemistry dictionaries, was:

| | | |
|---|---|---|
| A compound | is | two or more elements or compounds which join together chemically and change properties. |
| token | rel:int | value |

On several occasions, Ms. Armstrong reinforced this definition by comparing it to the one for *mixture,* which was presented using the negative of the characteristics which appear here (see Section 7.3.3).

Once the definition had been constructed, Ms. Armstrong, reading aloud from the text, introduced *water* as a compound and asked (as the text did) what it was made of:

| | |
|---|---|
| Teacher: | Who knows? What is water made of? |
| Male: | Electrons. |
| Teacher: | Electrons? |
| Female: | Elements. |
| Teacher: | Yes. It's made of elements. It's made of two elements. What are they? |
| Male: | Oxygen. |
| Teacher: | Oxygen and? |

| | |
|---|---|
| Female: | Hydrogen. |
| Teacher: | Hydrogen. Hydrogen and oxygen. Exactly. And the formula for water. Most of you have probably seen this. *(She writes it on the board.)* It's H two— |
| Male: | O. |
| Teacher: | O. That's the formula for water. So water is made up of *(reading from text)* "Hydrogen and oxygen. Hydrogen by itself is a gas." What is oxygen? |
| Students: | Gas. |
| Teacher; | It's also a gas. Okay. So hydrogen is a gas and oxygen is a gas. You join them together to become a compound and what form do they take? What state? |
| Male: | Liquid. |
| Teacher: | It's a liquid right? Water is a liquid? So you've got two gases that join together to form a liquid. Okay? So obviously water is a... compound. Right? |

Ms. Armstrong then brought the students' attention to the diagram of a water molecule in the textbook, asking "how many atoms are there altogether in this molecule? How many atoms in Mickey Mouse?"

The teacher did several things in the above discourse excerpt, using the visuals connected to it. She used a series of relations to identify water and its attributes. She offered water as an example of a compound, a fact which is apparent through the title of the section of the text:

| Water | — | A Compound |
|---|---|---|
| carrier | | attribute |
| X | is a type of | Y |
| X | is in the class of | Y |

With this concept in mind, Ms. Armstrong (following the text) continued to explore the attributes of water by asking what it is made of:

| It | is made of | two elements. |
|---|---|---|
| carrier | rel:int | attribute |

She then asked what those elements are:

| They | are | oxygen and hydrogen. |
|---|---|---|
| token | rel:int | value |

She provided the formula for water, $H_20$, in another token/value relation.

Once water had been identified as a compound and its attributes given, Ms. Armstrong (still following the text) examined the attributes themselves, requesting their attributes:

| | | |
|---|---|---|
| Hydrogen | is | a gas. |
| Oxygen | is | a gas. |
| carrier | rel:int | attribute |
| X | is a type of | Y |

With these in mind, the teacher presented a causal relation and asked for the resulting attribute:

You join them together to become a compound and what form do they take?

| | | |
|---|---|---|
| Water | is | a liquid. |
| carrier | rel:int | attribute |
| X | is a type of | Y |

She used the attributes here to provide evidence that water is a compound, based on the definition of compound and the taxonomy which the class had constructed earlier. This taxonomy offered gas as a property, and when these two gases join, they become liquid, which the taxonomy considered to be a different property. The property changed, so the result of the joining must be a compound because the definition states that a compound is two elements which join and change properties. Ms. Armstrong, therefore, used a series of relational constructions to define and classify water, then used information that she and the students had defined and classified earlier to construct a causal argument which could be used as proof for the key carrier/attribute relation being studied: *Water is a compound.*

Finally, Ms. Armstrong offered a visual representation of the formula she had stated, asking about the number of atoms and elements in the molecule. She had not yet defined the term *molecule* explicitly, but she used the term as a label for the drawing. She moved between the diagram of the molecule and the formula for it, asking various questions concerning the number of atoms of each element present, then asked what the diagram and the formula represented:

| | |
|---|---|
| Teacher: | That is one what of water? |
| Female: | Molecule. |
| Teacher: | One molecule of water. This is a molecule. The atoms joined together are a molecule. If you take one of the oxygen atoms away do you still have water? |
| Male: | No. |

| | |
|---|---|
| Teacher: | No. If you take the hydrogen away do you still have water? |
| Male: | No. |
| Teacher: | No. Can you take any part of this away and still have water? |
| Students: | No. |
| Teacher: | No. So... one molecule of water is the smallest piece of water you can get. Otherwise it's not water. Okay? |

Through this discourse, Ms. Armstrong related *molecule* to *compound* in two ways. First, she used a construction similar to the students' definition of compound:

| | |
|---|---|
| molecule: | The atoms joined together... |
| compound: | Two or more elements or compounds which join together... |

This suggested that in some way, compounds and molecules are the same thing since they have similar things joining together. Second, the teacher stated that one molecule of water is the smallest piece of *water,* which the students know is a compound:

| | | |
|---|---|---|
| Water | is | a compound. |
| carrier | rel:int | attribute |

| | | |
|---|---|---|
| The smallest piece of water | is | a molecule. |
| carrier | rel:int | attribute |

This comparison provided a parallel which the students used to construct a definition later on the same day:

| | | |
|---|---|---|
| A molecule | is | the smallest pure piece of a compound. |
| token | rel:int | value |

Not only was *water* used as an example of a compound for which students drew a molecule and counted the elements and atoms, Ms. Armstrong followed the textbook by discussing sugar, salt, baking soda, carbon dioxide, rust, penicillin, methane, butane, octane, petroleum jelly, and plastic as well as the compounds found in food, such as carbohydrates, proteins, and fats. She had the students count the atoms and elements in each of these compounds and focused on a few which the students drew in their notebooks. Although Ms. Armstrong presented the concepts of ionic and covalent bonding, the students did not learn how to write the formulas for more than the few compounds she used as examples in her explanations.

In sum, Ms. Armstrong used the textbook's explanations, visuals, and questions to teach the concept of compounds, frequently drilling students about what was written in the text.

These questions were not designed to probe students' background knowledge, although the oral responses in class showed that the students were familiar with some of the information presented, such as the elements which make up water. The teacher had the students construct definitions for both compounds and molecules, and also asked them to draw diagrams of a limited number of compounds, count their atoms and elements, and write their formulas. Ms. Armstrong made connections between compounds and properties, using *water,* a familiar compound with familiar elements (based on the speed with which the students identified them), as the example which showed how the properties—states of matter in her example—of the elements changed when they joined to create water. Moreover, because the students appeared to be familiar with water as a compound, it was also used to facilitate the understanding of the definition of molecule.

### 7.3.3 Building up an understanding of *mixtures*

As with compounds, page five of the textbook offered a definition which it claimed scientists use for *mixtures:*

> the word **mixture** means any group of elements or compounds which are together but not joined the way a compound is. Most of the things around us are mixtures. Some you know are air, fruit juice, paints, and soaps.

According to the textbook, and consistent with the information Ms. Armstrong presented to the students, mixtures are one of four things which make up matter, along with *elements, atoms,* and *compounds.* Definitions for these were introduced, drilled, and tested in early January and then left until mid-May when both compounds and mixtures were revisited and re-defined.

The textbook definition contrasted mixtures and compounds, stating that mixtures are not joined the same way as compounds are. In fact, the negative played a key role in the way that the term *mixtures* was redefined when the topic was reintroduced in May:

| | |
|---|---|
| Teacher: | Okay. Definition of a mixture. All right. Give me some characteristics of a mixture then. Okay. A mixture is not joined together. Okay. It's not— |
| Male: | Not change properties. |
| Teacher: | Does not change properties. |

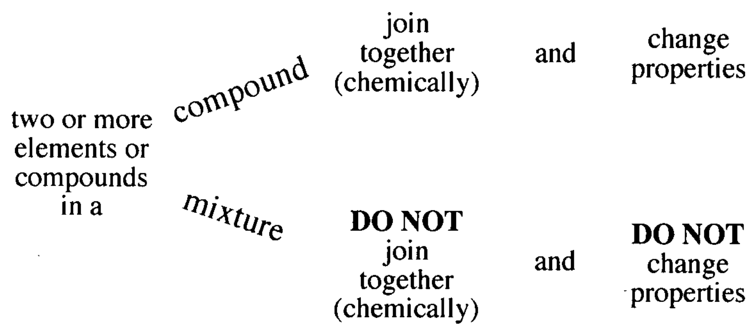
Vicki: By physical means.
Teacher: It tends to be separated by physical means. Good. What else?
Vicki: No chemical change occurs.
Teacher: No chemical change. Anything else?
Male: That's it.
Teacher: That's it? Okay.

The definition which was written on the board for the students to copy into their chemistry dictionaries was:

| | | |
|---|---|---|
| A mixture | is | two or more elements or compounds which do not join together and do not change properties. |
| token | rel:int | value |

This definition constructs a meaning of mixtures which is opposite to compounds in a binary, positive/negative way. The two terms are therefore related conceptually; if a student does not understand what a compound is by its definition, he or she will also not understand mixtures, as they both use the same concepts *(join chemically, properties),* but in polar opposites, as Figure 7.12 shows. In this way, the definitions which the students wrote in their chemistry dictionaries and which Ms. Armstrong drilled and quizzed were dependent on each other as well as with other terms *(properties, elements, join chemically),* all interlocked.

**Figure 7.12: Polarity in the definitions**




The textbook presented six paragraphs about mixtures which the teacher and students read, and interestingly enough, these were situated within the chapter entitled "Compounds," suggesting by this inclusion that compounds include mixtures. The text offered a few examples of mixtures within these paragraphs (e.g., salad dressing), showing how the properties of the individual components are still apparent in the mixture. It stated that "a mixture can easily be divided into its parts" (Scott, p. 31), and gave a straightforward example using color as the property which helped separate a mixture of various, different colored coins. The next two examples the text presented, hair spray and a gold chain, were not ones which appear to be easy to separate, and no suggestions beyond a hand separation of the coins were offered.

As stated earlier, Ms. Armstrong often used *if... then...* causal constructions to reinforce the information in the textbook through a style of questioning which appeared drill-like:

| | |
|---|---|
| Teacher | *(Reading from text.)* "Water is usually seen as a liquid. It is clear. It mixes with many things easily." Okay so it's easy to make a mixture with water. So if you add coffee what do you get? |
| Male | Coffee. |
| Teacher | You get a drink called coffee. Okay. If you mix it with salt? If you put salt in the water does that mix easily? No? |
| Male | Yes. |
| Teacher | Yes. It does. What about sugar? |
| Male | Yes. |
| Teacher | You put sugar in water it will dissolve. Okay it will mix easily. All right. *(Reads again.)* |

The students offered short answers to these questions which suggested that they understood the causal relations concerning mixtures.

A handout on mixtures which was given to the students offered six ways to separate mixtures, along with an example of a mixture each would separate:

letting something settle: sand and water
distillation: alcohol and water
evaporation: sugar and water
using a magnet: wood chips and iron filings
physically separating with your hands: peas and beans
using a centrifuge: blood

These were discussed in class about two weeks prior to a class group problem-solving activity which Ms. Armstrong assigned to show how mixtures could be separated into their various components by physical means. In this activity, Ms. Armstrong had the students work in groups to figure out how to separate the following mixtures:

1) dried coffee and sugar
2) salt and water
3) iron filings, gold, salt, and sand

She made sure that the students understood what the individual items were in the three questions and then gave them time to discuss the separation methods in groups, which most students did in their first languages. The teacher also encouraged the students to think about the properties of metals to help them solve the third problem.

The students had no trouble with the first question. They suggested that these two parts could be separated by using tweezers and, if necessary, a magnifying glass. The second question took more probing by the teacher; although the students quickly offered *evaporation* as the method, Ms. Armstrong was the person who elaborated on what would actually occur, using a temporal relation with causal inferences:

Teacher: The water will evaporate into the air and the salt will be left.

The third problem posed the biggest challenge and produced the most teacher-led discourse as she tried to help the students understand how to separate all the items. By consulting the handout on mixtures, the students knew that they could use a magnet to separate the iron filings, but they thought perhaps the gold could be separated in the same manner. Upon discovering that this was not so (Ms. Armstrong told them this, but did not elaborate on which metals had this magnetic property), the students could not figure out how gold could be separated. Some suggested melting the gold, knowing that sand would not melt easily. Nobody thought of panning for gold, but when Ms. Armstrong mentioned it, one student was able to describe what this process was (see Section 7.2.2 for his sequential explanation and the teacher's recasts).

A possible and likely explanation for why these students had trouble solving some of these problems relates to the topic of physical properties. A straightforward property, color, had been mentioned on several occasions, so it was an obvious choice when considering two solids which have different colors (the coffee and sugar). Evaporation was somewhat trickier for them because solubility as a property had not been introduced, defined, or given examples for. The students' answers for this question and for the salt in question three were therefore dependent on background knowledge. Magnetism, as a property, was also not discussed in class, and although the students were directed to consider whether the elements they examined in their observation activity were light or heavy, no mention of the relative mass or density of elements was made. How could the students know if gold was magnetic or heavy unless they had previously studied these topics? The taxonomy which had been constructed through the classroom discourse of the past few months did not include enough properties for students to solve all three problems.

At the end of May, after approximately two weeks of discussing compounds and mixtures (among other topics), Ms. Armstrong had the students do a chromatography lab. The lab involved using chromatography strips to test green, purple, yellow, red, and blue to see which colors were mixtures and which were pure. (The steps carried out to do this lab were discussed in some depth in Section 7.2.2.) As the teacher orally directed the students through the written conclusions, she asked:

| | |
|---|---|
| Teacher: | From our observations... from our data table... Okay? From this? Which ones of these colors are mixtures and which ones are pure colors? Which are mixtures first of all? |
| Male: | Yellow. |
| Students: | Yellow and green and purple. |
| Fred: | Oh oh oh! Green and purple! |
| Teacher: | Green and purple are mixtures. Yellow red and blue are... pure colors. And how do we know? |
| Fred: | Because purple and green separated. |
| Teacher: | Okay. Purple and green separated... and blue did not. Or yellow did not. Okay? Your conclusion is actually fairly simple. |

She also had students state the components which made up both green and purple.

The discourse excerpt above clearly illustrates the two types of patterning which Halliday (1998) discussed. Ms. Armstrong first had the students determine which were mixtures and which were pure colors, therefore classifying them in carrier/attribute constructions:

| | | |
|---|---|---|
| Green and purple | are | mixtures. |
| Yellow, red, and blue | are | pure colors. |
| carrier | rel:int | attribute |
| (X | is in the class of | Y.) |

The teacher then asked the students to reason logically about the evidence for their conclusions, and Fred offered the answer using *because,* a causal conjunction. Finally, having the students list the components of each mixture encouraged them to examine their chromatography strips once again to find the various colors which the mixtures separated into, creating small part/whole taxonomies of color mixtures.

Whereas this chromatography lab connected well with the "characteristic" of mixtures which concerned their easy separation—the chromatography paper illustrated this well—it is difficult to see how the lab related to the definition of mixture which Ms. Armstrong co-constructed with the students, drilled, and quizzed them about. The definition stated that in mixtures, the elements or compounds do not join and do not change properties. So are colors elements or compounds? Also, the experiment showed that when colors are mixed together, new colors are formed. Color was listed as a property or characteristic, and so the color change which occurred when the two components were mixed contradicted the definition which said that the property (color) does not change. The chromatography lab, in other words, may have caused some confusion for students who were struggling to understand the concept of mixtures and compounds and to see how the definitions were being applied to the practical labs.

To summarize, the teaching of mixtures was carried out by Ms. Armstrong by having the students define the term, quizzing and drilling them on the definition, and providing activities which encouraged them to reason both about how mixtures could be separated (the three questions) and what evidence there was for claiming something was a mixture (the chromatography lab). Yet as the above discussion suggested, the taxonomy of physical properties which had been constructed through the discourse of the classroom did not include enough information to reason about the separation of the mixtures in the first activity, leaving the students dependent on background knowledge to attempt the task. Moreover, the second activity did not appear to be supported by the definition which had been constructed, a definition which was highly interlocked with that of *compound.* The students may have been able to repeat the definitions they had studied, but without a clear understanding of this topic, it is understandable that they would have trouble constructing logical causal explanations about it.

## 7.4 The language of the interviews

In early April, after three months of studying chemistry, one group of three boys and one group of two girls began meeting with the researcher at lunch time to talk about what they were learning and to do some problem-solving activities in English. These students were considered by Ms. Armstrong to be five of the most responsible and mature in the class. The problem-solving tasks they did were chosen by the researcher to reflect the concepts the students were studying in class, but the tasks also required the students to attempt an application of the concepts and to explain their conclusions. The dates of the interviews and the topics of the problem-solving tasks are presented in Table 7.2.

**Table 7.2: The interviews with the ESL high school students**

| Date (boys) | Date (girls) | Problem-solving task |
|---|---|---|
| April 2, 2001 | April 6, 2001 | Electrons, protons, and neutrons |
| April 24, 2001 | May 14, 2001 | What makes an element reactive? |
| May 8, 2001 | May 24, 2001 | Physical changes |
| May 22, 2001 | May 30, 2001 | Electrons and bonding |
| June 5, 2001 | June 11, 2001 | Bonding |

### 7.4.1 The ESL students' use of technicality and grammatical metaphor

Although these five students met for the interview sessions for a total of approximately two and a half hours, there was not a great amount of talking done during this time. In fact, the students uttered only 5273 words, of which 878 were processes. As Table 7.3 shows, there were 106 different processes used, representing seven categories. Material processes were the most common of these different processes, accounting for 71.7% of the 106 processes used, followed by mental processes (11.32%), relational (7.55%), causal and verbal (2.83% each), behavioral (1.89%), and existential (1.89%). Unlike the mainstream students, these students did not use any temporal processes or processes of evidence.

Examining the average number of occurrences per process helps to reveal the dependence the ESL speakers had on particular processes. Table 7.4 rearranges the data

**Table 7.3: The 106 processes in the ESL interviews**

**Causal processes (3; 2.83%)**

| | | | |
|---|---|---|---|
| cause | 5 | form | 3 |
| create | 3 | | |

**Material processes (76; 71.7%)**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| act | 1 | complete | 1 | get | 7 | make sure | 1 | share | 9 |
| add | 1 | cook | 1 | get in | 3 | meet | 1 | shrink | 1 |
| attract | 1 | cover | 1 | get into | 7 | melt | 7 | spell | 3 |
| boil | 1 | cut | 1 | get off | 1 | message (send a) | 1 | spit | 1 |
| build | 1 | do | 8 | get through | 4 | mix | 9 | spill | 1 |
| burn | 7 | draw | 12 | get together | 4 | move | 3 | stay | 1 |
| carry out | 1 | eat | 6 | give | 4 | pass | 1 | stick | 1 |
| change | 13 | evaporate | 2 | go | 31 | pshew (explode) | 1 | take | 3 |
| choose | 1 | exchange | 1 | heat | 1 | pull | 1 | touch | 5 |
| choose to pull | 1 | explode | 8 | hold | 2 | put | 28 | try to explain | 1 |
| combine | 5 | fill | 1 | hurt | 1 | react | 24 | turn | 1 |
| come | 2 | finish | 1 | join | 42 | react to be | 1 | use | 4 |
| come in | 1 | flow | 2 | jump | 1 | reactive (react) | 2 | wait | 1 |
| come into | 2 | focus | 3 | keep | 2 | rust | 2 | waste | 1 |
| come out | 1 | function | 1 | leave | 2 | separate | 5 | write | 2 |
| come up | 5 | | | | | | | | |

**Relational processes (8; 7.55%)**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| be | 211 | become | 32 | get | 17 | mean | 38 | turn | 1 |
| be called | 13 | be made of | 1 | have | 71 | | | | |

**Mental processes (12; 11.32%)**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| forget | 1 | imagine | 1 | mean | 9 | remember | 4 | think | 56 |
| guess | 3 | learn | 1 | need | 12 | see | 11 | understand | 5 |
| know | 19 | matter | 1 | | | | | | |

**Verbal processes (3; 2.83%)**

| | | | |
|---|---|---|---|
| ask | 2 | say | 6 |
| explain | 5 | | |

**Behavioral processes (2; 1.89%)**

| | |
|---|---|
| talk | 1 |
| watch | 1 |

**Existential processes (2; 1.89%)**

| | |
|---|---|
| happen | 1 |
| there is / are | 17 |

from Table 7.3 to present these averages. This table shows that the highest occurrences per process appear in the categories of relational, mental, and existential processes. A high average in the existential category is to be expected, given the small number of processes to choose from to construct existential clauses. Twelve different mental processes were used to construct 123 clauses, also suggesting that the students relied on these 12 processes quite heavily. What is particularly interesting, though, is the average number of relational clauses per process: 48 occurrences for each of eight. In other words, out of the 878 clauses which were constructed, 384 were relational (43.74%), and only eight different processes constructed those 384 relational clauses. Compared to Mr. Peterson's students, the ESL students seemed quite limited in their repertoire of these process choices. These findings are consistent with Schleppegrell (1998), who observed that the grade seven and grade eight ESL students in her study relied heavily on a small set of verbs for their descriptions.

The processes at times were used in ways that sounded unusual, potentially marking the speaker as a non-native speaker of English. For example, one construction which occurred in the speech of four of the five students as they attempted to explain why some elements are considered more reactive than others was the pattern *easy to X,* as in the following examples:

| | |
|---|---|
| Ken: | It's easy to burn if not not as reactive. |
| Tony: | It's very easy to react if it meets air. |
| Vicki: | I mean the element is easy to join. |
| Belinda: | Easy to join (xx). |

**Table 7.4: The average number of occurrences per process**

| Process type | No. of processes (total = 106) | | Frequency (total = 878) | | Average number of occurrences per process |
|---|---|---|---|---|---|
| Causal | 3 | 2.83% | 11 | 1.25% | 3.67 |
| Material | 76 | 71.7% | 327 | 37.24% | 4.3 |
| Relational | 8 | 7.55% | 384 | 43.74% | 48 |
| Mental | 12 | 11.32% | 123 | 14.01% | 10.25 |
| Verbal | 3 | 2.83% | 13 | 1.48% | 4.3 |
| Behavioral | 2 | 1.89% | 2 | .23% | 1 |
| Existential | 2 | 1.89% | 18 | 2.05% | 9 |

The meaning which the students were constructing with this type of pattern could be rephrased as "it burns easily" or "it reacts very easily" or "the element joins easily," yet it appears as though the students did not know the adverbial construction and instead relied on their *easy to X* resource. This pattern occurred nineteen times throughout the interview data. Moreover, Tony used a similar construction with other adjectives in place of *easy* to help him explain his ideas about other concepts:

| | |
|---|---|
| Tony: | Because the heat in the air it's not ver— it's not very much to keep the water in the liquid form so... |

In Tony's explanation of why rain turns to snow, he used a pattern similar to *easy to X* when he stated *it's not much to keep,* but in this context the meaning he was making was something like the following:

> Because there isn't enough heat in the air to the keep the water in liquid form...

or

> There isn't enough heat in the air to keep the water in liquid form so...

Tony also used the construction "it's not possible to" three times, "it's able/unable to" three times, and "it's not enough to" once, suggesting that he found the *easy to X* pattern productive for a variety of meanings, all of which helped him explain his understanding but which marked him as a non-native speaker of English.

These students, despite being recommended as the best and most studious in the class, had considerable difficulty finding the words and phrases they needed to construct their ideas. Their lack of resources often resulted in false starts, repetition, and unfinished thoughts, forcing the listener to work to make sense of the explanations. The following excerpt, in which Tony and Ken are trying to explain physical change, illustrates the problems the students had:

| | |
|---|---|
| Tony: | Mm. Physical change is like um you can... um it's by some... like... like um... like um... what's that called... when you cook when you boil the water and it will be... um... |
| Ken: | It is um... something like the caps inside like cap? Mm... cup? And on the top what's that called like a cap. |
| Researcher: | Mm-hmm? Lid? Mm-hmm? |
| Ken: | Yeah when the water gets when the water hot when the water is hot... you you sometimes you can see... in that cap uh in the other side of that cap is... something uh water.... Yeah. |

In beginning his explanation, Tony made six false starts before asking for a vocabulary item ("what's that called") which he started twice and then abandoned. Ken tried to ground his explanation in a description of an item, but was unable to succeed well enough to make the researcher understand what it was that he was trying to label. Although he responded positively to the researcher's offering, he subsequently rejected it and continued his explanation attempt. He also made several false starts as he tried to choose the appropriate process to use (the water *gets* hot) before finishing his explanation. Both boys opted for a temporal *when... then...* construction to explain physical change, but both found it difficult to complete the temporal relation smoothly:

> When you boil the water, it will be—
> When the water gets hot, you can see— water.

Ken's explanation was almost complete, but he could not think of the term *water vapor,* which would have made his explanation correct despite his difficulties. This problem with searching for words, making false starts, repeating words, and leaving ideas unfinished was common in the speech of these five individuals.

The discourse of the interviews revealed various nouns, or entities, related to science. (Table 7.5 shows the frequency of these terms.) Most of these (40) were categorized as concrete specialized and involved the names of the elements and other aspects of the periodic table. Abstract technical terms, of which there were 34, were mostly related to the atom, and were sometimes used incorrectly, suggesting that the students may not have been aware of their scientific meanings. A salient example of this was the use of the technical term *element,* which was used in a way which revealed an incorrect understanding:

> Tony: Two elements or three... elements... become another kind of element.
>
> Kevin: Chemical change is like... two or more elements. Sometimes they join together and they make the other kind of element.

These boys appear to be confusing *element* and *compound,* using the former as the term for both meanings. Tony used *element* this way on four occasions, but he also used *thing* and *compound* in similar situations, shifting between the everyday vocabulary ("thing") to abstract technical terms.

The data also revealed entities that are considered metaphoric processual, such as *information, definition, reaction, oxidation, evaporation,* and *change*. (A complete list of these scientific entities as used by the ESL students can be found in Appendix 6.) There were five technical processes, such as *attract* and *evaporate,* and ten technical attributes, such as *reactive, ionic,* and *neutral.* Although there were a few examples of students alternating between processes and participants (e.g., *mix* and *mixture, evaporate* and *evaporation)* or processes and attributes (e.g., *react* and *reactive),* the students often seemed to have trouble using more than one form of a term; in other words, their control over grammatical metaphor was very limited. This was clearly illustrated by Vicki and Belinda as they discussed reactive elements:

| | |
|---|---|
| Belinda: | When they join together they will have reactive? |
| Vicki: | ... They... they'll reactive. I mean the element is easy to join. It's easy. Of course some elements not join... not reactive. |

Whereas the girls had particular trouble with this morphological taxonomy, the boys struggled to find the nominal and adjectival form of *explode,* as will be discussed later. Other pairs include *rust* and *rusty, negative* and *negatively.* These types of morphological sets appeared to present problems in the students' discourse.

### 7.4.2 The ESL students' resources for logical reasoning

Because these interviews involved problem-solving tasks as well as explanations, it was anticipated that the language the students used would change depending on the task. While this was certainly noticeable in cases where the students were drawing and labeling and therefore asking for spelling help and commenting on the progress, the differences at other times were more subtle. The first task, on electrons, protons, and neutrons, offered some of these differences. While the students were focused on the task of labeling each particle according to the direction it should go in (towards the positive side, the negative side, or straight ahead), they simply commented on the graphic and confirmed their understanding of which particles had which charge:

| | |
|---|---|
| Keifer: | We don't this is neutron right? |
| Tony: | Yeah. |
| Ken: | Yeah here is negative side and this is the positive side |
| Keifer: | So um |
| Ken: | This is a particle. |
| Tony: | Neutron has the negative charge right? |
| Ken: | [So it will |

| | |
|---|---|
| Keifer: | [Neutron? Neutron has no charge. |
| Ken: | Yeah. Yeah. |
| Tony: | Yeah neutron. Electron has... |
| Ken: | Electron is uh electron is um... [positive. |
| Tony: | [I think electron is is... negative... |

There were exophoric terms in the discourse, such as *this* and *here* and with the exception of Tony's mental process, *think,* the speakers used the relational processes *be* and *have* as they described and classified what they saw. They did not use causal discourse until Keifer justified his decision by stating the following:

> So I think... like a magnet... right? A plus charge and... a minus charge gets together.

This was the group's first attempt to justify their answers and it involved both a material process, showing what the particles *do* rather than what they *are,* and the causal marker *so.* The students agreed with Keifer on this and then called the researcher over to tell her what their decision was and why they believed it was so:

| | |
|---|---|
| Researcher: | Okay... what's your group decision? |
| Tony: | Uh this one is proton and this one is electron and this one is neutron. |
| Researcher: | Mm-hmm? |
| Ken: | Because uh... uh... because proton is positively charged and it's must goes the negatively side. |
| Keifer: | Like a magnet. |
| Researcher: | Mm-hmm? |
| Keifer: | Um... plus charge and um... minus charge um gets together right? So... it's all this... Proton is this side. |
| Tony: | And neutron has [no charge |
| Ken: | [It has no charge. |
| Tony: | so it will just go straight. Yeah. |

When justifying their answers to the researcher, the students' discourse did not lose its exophoric quality because the graphic which was at the center of the task was still in front of them for reference. Yet Ken took his explanation beyond what was visible by stating the proton's attributes and therefore where it must go. Keifer explained that plus and minus charges go together (a general rule), then involved the context to identify which one was the proton based on this rule. Tony kept his explanation in general terms by stating the neutron's attributes and how these attributes affected the particle.

The difference between the language the students used to figure out the task and the language used to explain their answers differed primarily in the boys' attempts to justify their responses with reasons, and these reasons involved both relational and material processes as well as causal discourse resources such as *because* and *so,* which they used to indicate the theory behind their claims. The same situation arose in the girls' interviews, except that when they worked together on the task, they frequently identified the particles by the letters they had been given in the diagram:

Vicki: The electron is the A particle. The proton is C.

These labels were replaced with the exophoric term *this* when the girls explained their results to the researcher.

**Table 7.5: The causal language features present in the ESL interview data**

| **Language Features Associated with TIME** | no. of times |
|---|---|
| after | 1 |
| and | 50 |
| and then | 13 |
| before | 1 |
| finally | 1 |
| first | 1 |
| now | 1 |
| so then | 8 |
| still | 1 |
| then | 18 |
| when | 46 |
| **TIME participants (2)** | 2 |
| **TEMPORAL processes** | 0 |
| **TIME circumstances (9)** | 23 |
| **PLACE circumstances** | 121 |

| **Language Features Associated with CAUSE** | no. of times |
|---|---|
| because | 21 |
| if | 26 |
| so | 91 |
| so that | 2 |
| to | 5 |
| **CAUSAL processes** | |
| form | 2 |
| give off | 1 |
| make | 17 |
| **CAUSE participants** | 0 |
| **CAUSE circumstances** | |
| because [of] | 1 |
| **MEANS circumstances** | |
| by the lens | 3 |
| by the chemical change | 2 |
| by the optic nerve | 1 |
| **LEXICAL DENSITY** | 39.8 |

| **Other Language Features of Academic Explanations** | no. of times |
|---|---|
| **PASSIVE VOICE** | |
| called | 10 |
| charged | 1 |
| evaporated | 1 |
| exchanged | 1 |
| finished | 1 |
| joined | 4 |
| made | 1 |
| melted | 1 |
| mixed | 2 |
| separated | 1 |
| shared | 1 |
| supposed *(prediction)* | 2 |
| **ENTITIES** | |
| metaphoric processual (14) | 44 |
| metaphoric quality (4) | 18 |
| abstract technical (34) | 267 |
| concrete specialized (40) | 285 |
| abstract semiotic (1) | 1 |
| abstract institutional (1) | 1 |
| concrete everyday (1) | 1 |
| **TECHNICAL processes (5)** | 37 |
| **TECHNICAL attributes (10)** | 57 |

Supporting Flowerdew (1998), who observed that ESL students relied on a small set of causal conjunctions to express causality, Table 7.5 shows that the conjunction *so* was by far the most popular of all conjunctions, occurring 91 times (31.82%) in the students' explanations:

| | |
|---|---|
| Keifer: | The electron |
| Ken: | This one this one. |
| Keifer: | is negative charge so it's is it's go to here. |
| Vicki: | Proton has a positive charge so... proton is going to be this way. |
| Ken: | And uh in the other... element... in the other element... yeah the other element will soon... because it's less so it's very it's... need the other... other element's electron like too much so that (neutron?) maybe neutron too full... |

On several occasions, a prior discussion led to an observation by another student which began with the conjunction *so:*

| | |
|---|---|
| Tony: | Uh when the... when the heat is not enough and the |
| Ken: | Water. |
| Tony: | water will be |
| Ken: | Become. |
| Tony: | will becomes to liquid and becomes solid. |
| Ken: | So you can see it is ice. |

There were also examples of *so* introducing a comment which was linked to what the students were doing rather than what they were saying. Vicki and Belinda often took turns drawing or writing as they did the problem-solving tasks and they made comments and observations about what they were putting on paper. While drawing hydrogen and oxygen atoms to show how bonding might occur using the full outer shell theory, the two girls used *so* frequently as they drew and wrote to state what the results of their efforts were indicating so that they would know how to continue:

| | |
|---|---|
| Vicki: | Oxygen... has... six... electron in its outerbal shell. |
| Belinda: | In outer shell. So we need two. |
| Vicki: | So we need two more... |
| Belinda: | So we need... that's six? |
| Vicki: | Yea. Six... electron... in the... |
| Belinda: | Outermost shell. |

All these uses of *so* suggest a kind of causality in that what has already occurred plays a causal role in the result, indicated by a *so*-clause.

Although the students used only five types of causal conjunctions compared to eleven types of temporal ones, the frequency with which they used these, particularly *so,* shows that they favored causal constructions slightly over temporal ones, 145 to 141. Temporal *when* was used 46 times (16.08%), roughly half the frequency of *so,* and only four fewer times than temporal *and* (17.48%). The word *and* was used both as an additive conjunction, simply joining two ideas, and as temporal one in which the conjoined ideas were linked sequentially:

Tony: When you um... when you put two... two wires into it and one is the negative one and another is positive and when the... electricity goes through the water and the... hydrogen and... oxygen will be separated and... go into the air.

Tony used both the additive *and* and the temporal-sequential one as well as *when* to explain how water can be separated into hydrogen and oxygen, as shown in Table 7.6. The conjunction marked by an asterisk creates an unusual construction because *when* is typically paired with *then* and not *and* when a second conjunction is used. Sequence is still implied in this odd construction, however, because putting electricity through the water is a necessary precursor to the separation of the hydrogen and the oxygen.

**Table 7.6: Tony's explanation of chemical separation**

| Conjunction | Topical theme | Rheme |
|---|---|---|
| When | you | put two wires into it |
| and (add.) | one | is the negative one |
| and (add.) | another | is positive |
| and (add.) when | the electricity | goes through the water |
| *and (seq.) | the hydrogen and (add.) oxygen | will be separated |
| and (seq.) | | go into the air |

The students had limited resources associated with time and cause with which to construct their explanations, as Table 7.5 indicated. Most of the circumstances of time occurred during the students' explanations of phase changes and referred to the seasons. Most of the place circumstances revolved around electrons *in* the outer shell. There were no participants of cause or temporal processes, and only one causal circumstance which was not a complete construction:

| | |
|---|---|
| Ken: | No it's because... evaporation. |

Circumstances of means, although rare, did occur, particularly during the students' explanation of the eye, which was elicited during the first interview to build rapport with the students and to find out what they had done in science before the chemistry unit began:

| | |
|---|---|
| Tony: | When the light get through the cornea and focused by the lens and touch the |
| Keifer: | And touch the sclera. |
| Ken: | Sclera. Yeah. |
| Tony: | And then the (xx) is |
| Ken: | goes through the— |
| Keifer: | Goes through the optic nerve. |
| Ken: | Yeah to the |
| Keifer: | Brain. |
| Ken: | Go to the go to the brain by the optic nerve. Okay. |
| Keifer: | It's that. |

The lens is the means by which the light is focused, but Keifer comments on *where* the light goes ("through the optic nerve") whereas Ken highlights *how* it gets to the brain ("by the optic nerve"). The only circumstance of means used to explain concepts in the chemistry unit was "by the chemical change" when talking about how compounds are joined together.

The ESL students used twelve different passives in twenty-six constructions, although eleven of these involved *called* or *made* in relational clauses such as "what's that *called*" and "water *is made of* hydrogen and oxygen." The passive "joined" was used four times when talking about bonding, as in Tony's statement that "compounds are joined together by... the chemical change." There were two constructions using *supposed,* both creating the meaning of prediction using non-human participants, as in "I thought the formula of oxygen is supposed to be $O_3$," rather than a meaning of obligation, or what the students were supposed to do.

The students constructed various types of temporal and causal relations as they explained their understanding of the various science topics which were presented in the interviews. Table 7.7 shows the frequency of the main temporal and causal relations and

**Table 7.7: The temporal and causal relations in the ESL interviews**

| | | | |
|---|---|---|---|
| (X)* because Y | 1 | (if X), then Y | 3 |
| X because Y | 11 | if X, then Y | 15 |
| X because...** | 1 | if X, then... | 7 |
| X because not Y | 1 | (X), if Y | 1 |
| X because not... | 1 | X, if Y | 2 |
| not X because not Y | 3 | X if not Y | 1 |
| not X because not... | 1 | if not X, then not Y | 1 |
| not X because Y | 2 | (when X), then Y | 11 |
| because X, Y | 1 | when X, then Y | 25 |
| X, so Y | 65 | when X, then... | 13 |
| X, so... | 17 | X when Y | 6 |
| X, so not Y | 4 | when X, then not Y | 1 |
| not X, so Y | 2 | when not X, then Y | 1 |
| not X, so not Y | 3 | do X and Y happens | 5 |
| X so that Y | 2 | do X and Y doesn't happen | 1 |
| X, so then Y | 7 | X, and Y | 42 |
| X, so then... | 1 | X, and... | 7 |
| X, then Y | 18 | X, and not Y | 1 |
| X and then Y | 13 | | |

**Less congruent forms**

| | |
|---|---|
| X to do Y | 4 |
| not X to do Y | 1 |
| X causes Y | 13 |
| X causes... | 2 |
| X does not cause Y | 2 |
| X because [of] Y | 1 |

*Items in parentheses indicate another speaker.

**Items with ellipses indicate an unfinished construction.

also illustrates occasions when the researcher co-constructed the relation (indicated by parentheses) and when the students were unable to complete the construction (shown by ellipses). Out of 297 congruent relations, 16 (5.39%) were co-constructed by both student and researcher, suggesting that either the students generally did not need much help setting up the relation they wanted to use, or that the researcher was unable to predict the types of responses being constructed by the students. The number of incomplete relations, however, was considerably higher, with 48 (16.2%) of all congruent relations aborted, most of these in constructions using *so* or *when,* and often involving repetition as the students sought for the words they needed:

| | |
|---|---|
| Tony: | And then in summer the... it's very hot so the... |
| Ken: | So |
| Tony: | So the [water |
| Ken: | [So the water was... was um... so the water was... |
| Tony: | So the water was |
| Ken: | The water was still |
| Tony: | Evaporation. |
| Tony: | Like um... when when oxygen... and... carbon right [turn] Um when you put them to get... when you put them together it's very easy to... become uh... uh... C-O. |

The high number of incomplete relations further illustrates the difficulties that these students had constructing their explanations.

The number of relations which are considered to be less congruent, or more grammatically metaphoric, amounted to a relatively small percentage of the overall number of these relations constructed, or 23 out of 320 (7.19%). Of these, only two were incomplete utterances and there were no co-constructed attempts. As Table 7.5 showed, there were only three causal processes used, with *make* accounting for the most occurrences (17). The process *make* was the only one of the three to occur in the *X causes Y* type of relation; *form* was used in the *X to do Y* and *do X and Y happens* constructions, and *give off* involved no *Y* in the particular context it appeared in, although the *Y* was inferred: "It gives off." The students also used the relational process *become* in ways which implied causality but which occurred in events rather than in actions:

| | |
|---|---|
| Tony: | Is very easy to combine with another element and become a new element. |
| Vicki: | So they can combine their outermost shell and become a new molecule. |

Out of thirty examples of *become* in the interview data, four were left unfinished and seventeen used *become* in constructions where it could have been replaced by a causal process such as *create*. In the remaining nine examples, *become* was used five times with adjectives (e.g., "become hotter") and four times in explaining phase changes (e.g., "becomes solid").

The number of actions, including those which used *make,* was relatively small compared to the overall number of clauses in the interview data. There were 41 actions, representing only 4.67 percent of the 878 clauses found in the corpus. Events accounted for 181, or 20.62 percent. The balance fell into neither category and included such constructions as relational clauses and projections.

Table 7.7 also shows that the ESL students used negatives in their causal and temporal relations 26 times out of the 320 constructions (8.13%). Whereas this is not a large percentage, the use of the negative appears to offer an interesting strategy for making meaning in different ways with a limited number of resources. Consider the following two comments about physical changes in water:

> Vicki: The weather get hot and hotter... so the snow... becomes hotter.
>
> Ken: And in the summertime... the temperature is getting hot... so no water no liquid. No it's because... evaporation.

Vicki used an *X, so Y* construction, linking two events causally but not offering much detail about what happens to the snow once it gets hot. Ken went beyond Vicki's explanation to comment about the result of the temperature increase and offer a reason for the result. He constructed this meaning by using an *X, so not Y* relation. There were, of course, other wording options, but the negative allowed him to construct the meaning he wanted.

A similar situation occurred in Tony's explanation. He talked about the temperature getting colder, but rather than expressing it this way, he used a negative to help him create a more grammatically metaphoric explanation, borrowing also from his productive *easy to X* construction and showing his understanding of heat in a *not X, so Y* relation:

> Tony: Because the heat in the air it's not ver it's not very much to keep the water in the liquid form so... the so they are become... so they are joined so they... are... and then so they are become the... snow. Yeah.

Tony later recast the beginning of his explanation in a *not X, so not Y* relation while maintaining his use of grammatical metaphor and the meaning he wanted to construct:

> Tony: So um in winter the heat in the air is not... enough so they can't keep the water in the liquid state... so—

The use of the negative in various locations within the clause complex appeared to offer these students more options to help them explain their understandings.

The use of the negative to construct explanations was not limited to the relations. It seemed also to reduce the demand for antonyms in other constructions, thereby doubling the students' linguistic resources. The following example illustrates how the three boys used the negative with both a process and an attribute to explain what they understood a reactive element to be:

| | |
|---|---|
| Keifer: | Then with we nitro so then then we saw a when it got hot water inside... like (xx) element and (xx) water. But go inside and *(makes a whooshing sound).* |
| Ken: | Explodes. |
| Keifer: | Explode. Yeah. Explode. |
| Tony: | Yeah. That means it's very reactive. |
| *(A few turns later they continue)* | |
| Tony: | And sometimes some elements don't react don't act don't react with uh... water or... or air or something else. |
| Ken: | Yeah. But some elements like iron? If you if you have water and put iron into water it will get ruh rust. It's uh that's uh... mm *(17 seconds pass.)* Uh... *(2 seconds pass.)* Not reactive. *(6 seconds pass.)* Not reactive with... it's like uh iron... iron put it into into water oh no not iron. Not not reactive with uh element. Put it into water and it doesn't make... isn't... it doesn't explode. |
| Keifer: | Yeah. |
| Ken: | It's not reactive. |

In the first few turns, Keifer recounted the video they had watched in which elements such as sodium and cesium were immersed in water. He used a sound rather than thinking of the appropriate process, and Ken offered the word he needed, "explodes." Tony sums up the recount by stating that the result meant that "it's very reactive." A few turns later, the boys attempted to contrast these very reactive elements with ones which are more stable. Tony turned the more metaphoric *reactive* into "don't react" to begin this contrast, although he had trouble recalling the word. After Ken introduced *iron,* he struggled with moments of silence as he tried to explain what happens with less reactive elements. Eventually he offered the negative of his earlier statement, and followed this with the negative of Tony's observation:

explodes → doesn't explode
very reactive → not reactive

In Ken's case, simply offering the negative of *explode* enabled him to complete his explanation without resorting to the more difficult grammatical metaphor which it appears he was attempting through his use of "it doesn't make" and "isn't":

> it doesn't make an explosion
> it isn't explosive

The use of the simple negative *not* in relations also seemed to help the speakers avoid the more linguistically demanding grammatical metaphor. Looking again at Tony's sentence, one can see how the word *so* is used repeatedly along with multiple negatives:

> So in winter the heat in the air is not... enough so they can't keep the water in liquid state... so—

Tony's main effort at grammatical metaphor is his nominalization, "heat in the air." A more grammatically metaphoric construction, however, might be

> Without enough heat in the winter, water changes from liquid to solid.

This construction, which appeared to be beyond Tony's linguistic ability, shifted the relation from *not X, so not Y* to *without X, Y.* It also reduced the number of clauses to one, creating a more lexically dense, grammatically metaphoric utterance characteristic of written language, but noticeable in the oral discourse of more expert speakers, such as the students in Mr. Peterson's mainstream class.

### 7.5 Summary

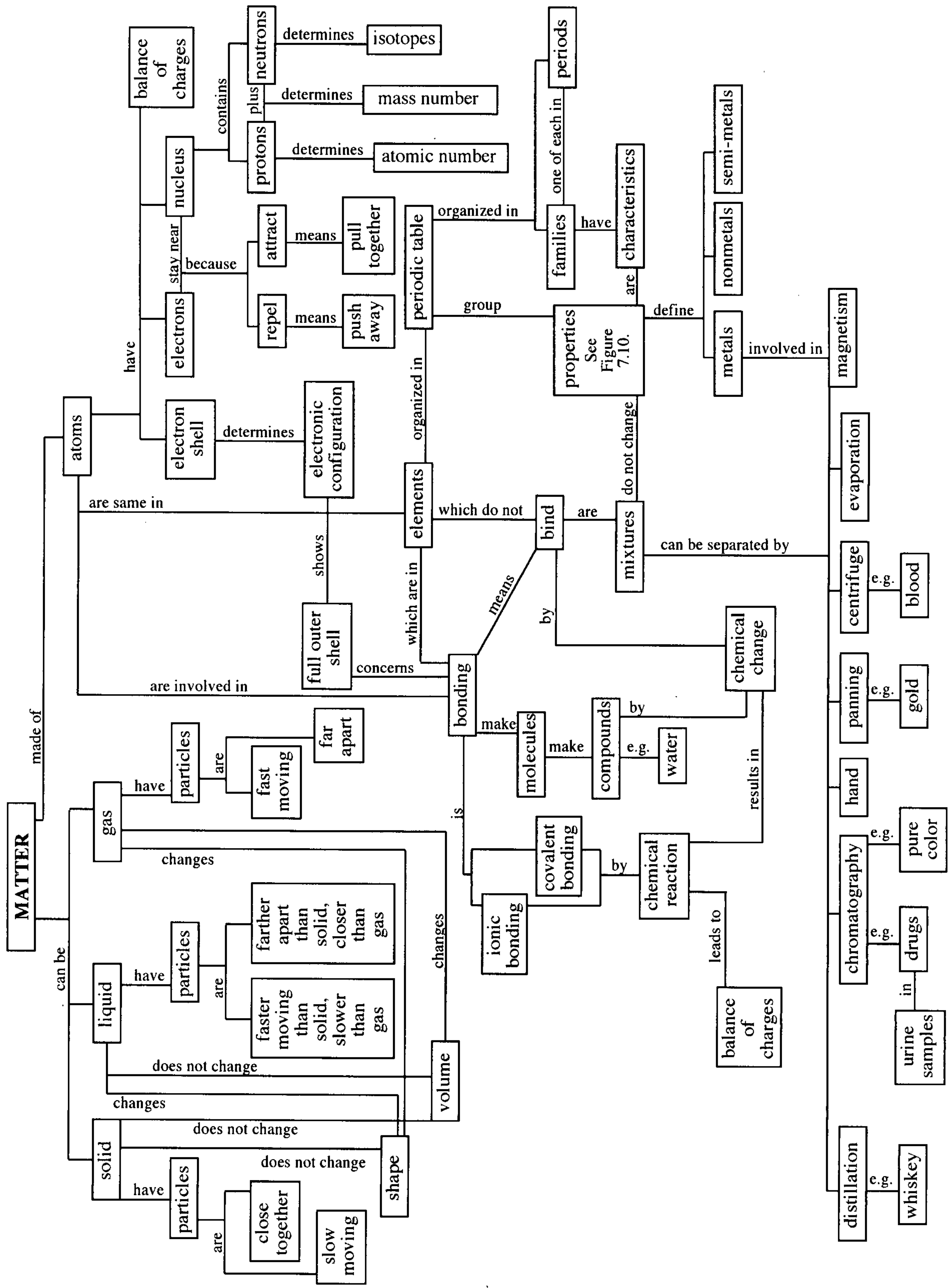
This chapter has attempted to show how the participants in Ms. Armstrong's ESL science class constructed knowledge. It examined the actions which the teacher took to teach the language and content, and the taxonomies which were constructed through this teaching. It also described the language which the students used to talk about and apply what they had learned, and discussed the difficulties they had constructing their ideas.

The discussion of the classroom interactions and activities illustrated Ms. Armstrong's questioning and drilling techniques. She presented the material to be learned either by introducing it herself or by reading aloud—or having the students read aloud—from the textbook, then questioned the students about the material in a drill-like manner. These questions targeted both types of Halliday's patterning as the teacher requested both definitions and *if X, then what* responses. Rarely did the questions deliberately probe the students' background knowledge or demand lengthy turns of logical reasoning. Moreover, when the students were directed to work in small groups to define or explain, the language they opted to use was their first language, even when prompted to use English.

Although the teacher's greatest emphasis appeared to be on defining terms, Ms. Armstrong also offered opportunities for the students to experience the knowledge she was constructing. The choices she could make were, however, limited by the fact that she was carrying out the science class in a regular classroom, usually used for teaching literature and English. The lab on matter clearly illustrated the idea of gas being matter as the students could see and measure displacement. But the observation activity which aimed to introduce students to some of the common elements and their physical properties provided limited experience because the elements were in glass and the concept of physical properties had not been adequately probed. The third experiential activity, the chromatography lab, was a questionable choice to aid in the construction of knowledge about mixtures because it appeared to contradict the definition which the students had been asked to learn. These activities, as with the other group activities, tended to be carried out in the students' first languages. Ms. Armstrong's questions to guide the lab activities, while moving from time to cause and specific to general, were as drill-like as her review questions.

Ms. Armstrong constructed small taxonomies as the need arose, typically to define terms. Some of these terms in these definitions were interlocked, using terms which also needed defining. The teacher attempted to build everyday taxonomies to provide a parallel model for the more scientific taxonomy she was attempting to create. The result, however, was that the analogies may have made it seem as though the scientific taxonomies could be as subjective as the everyday ones; this was particularly noticeable with the concept of properties, which as Section 7.3.1 described, tended to be problematic. The concept map which was constructed through the discourse of Ms. Armstrong's interactions with the students, following Novak (1998), appears as Figure 7.13.

## Figure 7.13: Ms. Armstrong's unit as a concept map



With regards to language specifically, Ms. Armstrong adopted a focus-on-form approach with the written work which the students put on the board. The products of much of the small group work were corrected for spelling, grammar, and punctuation before the students could copy them from the blackboard into their notebooks. In addition, when the textbook offered more grammatically metaphoric constructions, Ms. Armstrong simplified the language for the students; moving from the more congruent to the more metaphoric was rare.

The interview data revealed the difficulties the students had moving between the congruent and the metaphoric and the limited resources they had to construct meaning. Whereas they produced 106 different processes in 878 clauses with 71.7 percent of the processes accounting for 37.24 percent of the clauses, which averages out to 4.3 clauses per material process, they used only eight relational processes to construct 384 clauses, or an average of 48 clauses per relational process. These numbers suggest that compared to their resources of material processes, the students have a very small number of relational resources to draw from. Causal processes were few (3; 2.83%) and were used rarely (11; 1.25%), and no temporal processes or processes of evidence surfaced.

In general, causal conjunctions were favored slightly over temporal ones, and *so* was the most popular of the five used, accounting for 91 of the 145 causal conjunctions in the data (62.76%). *When*-clauses (46) were more popular than *if*-clauses (26). There were 11 different temporal conjunctions revealed. What was noticeable in the construction of the clauses with these congruent forms was the number of incomplete relations; 48 (16.2%) were aborted by the students as they struggled to build the meanings they sought to convey. Moreover, these students used negatives 24 times out of the 320 causal and temporal relations they constructed (7.5%). This use of the negative by the ESL students appeared to be a strategy which allowed them to double their linguistic resources and to avoid the more linguistically challenging grammatical metaphor. Finally, twelve verbs were used in the passive on 26 occasions, and most of the occurrences (10) used *called* in a labeling function.

The ESL students used few metaphoric processual entities or qualities compared to the number of abstract technical or concrete specialized terms. Words in the latter two categories can be taught as single entities which typically do not change depending on their place in the grammar, but the metaphoric entities require grammatical shifts, and such manipulation seemed to demand a more sophisticated linguistic ability than these students exhibited. Vicki's and Belinda's apparent inability to turn *reactive* (a metaphoric quality) into *reaction* (a metaphoric processual entity) illustrated this.

The five students who were interviewed were considered by Ms. Armstrong to be at the top of the class and ready to go into mainstream classes when school started the following autumn. The interviews illustrated the difficulties these students had using English to construct meaning, difficulties which were also evident in the classroom interactions.

It was also noted that Ms. Armstrong considered the students to be too immature for her to trust with science equipment, and without this type of hands-on approach she was left to rely primarily on the textbook and other text-based worksheets. The knowledge which was constructed in the class using the textbook as well as whatever activities Ms. Armstrong deemed suitable suggested that these may not have been adequate for bringing these ESL students to the same level as their mainstream peers.

# CHAPTER 8: FINDINGS AND DISCUSSION

## 8.0 An overview of the chapter

Chapter 4, Chapter 5, Chapter 6, and Chapter 7 each offered a detailed description of the interactions and activities which occurred in the four teaching contexts as well as a quantitative examination of the causal features present in the students' interview discourse. In this chapter, the key findings from the classroom and interview data of these four chapters will be brought together to respond to the two research questions:

1. How do the teachers and students develop causal explanations and their relevant taxonomies through the classroom interactions?
2. What are the causal discourse features being used by the students to construct oral causal explanations?

Section 8.1 will discuss the findings as they relate to research question one, and Section 8.2 will address research question two. Section 8.3 will discuss the connections between the two questions by comparing the development of conceptual understanding and causal language.

With the research questions answered, the chapter will continue by presenting implications for researchers and educators (Section 8.4), then by offering ideas for future directions for research (Section 8.5). The chapter will conclude by reflecting on the current study.

## 8.1 Responding to research question one

The classroom discourse data collected in the four contexts show how the primary grade teachers began by giving the students new experiences in the form of simple but structured lab experiments. In contrast, the high school teachers began with discourse, using a lecture-based approach which they peppered with hands-on activities to support the knowledge they were otherwise constructing linguistically. An examination of the discourse reveals that of the four contexts, Mrs. Montgomery and Mr. Peterson made clear connections between specific reflections which concerned the students' direct action and experience and the general reflection or theory which they were attempting to teach. The participants in Mrs. Sinclair's class worked primarily within specific reflection as they moved through the stations doing their hands-on experiments. The participants in Ms. Armstrong's class, on the other hand, worked mainly within the discourse of general reflection with few or unclear connections to experience and the specific reflection which accompanied it. These trends will be discussed in more detail below.

### 8.1.1 The primary classes

The primary students were involved in a social practice in which they were learning about magnetism with their teachers. This social practice is captured in Table 8.1.

**Table 8.1: The social practice of learning about magnetism**

| Social practice | Content/Action | Discourse |
|---|---|---|
| theory | (understanding) magnetism | general reflection discourse<br>classroom discussion<br><br>specific reflection discourse |
| practice | doing experiments with magnets | action discourse |

As experts, teachers are aware of the connections between practice and theory, between doing experiments with magnets and understanding magnetism. The task of the teacher is therefore to support her students so that they can also understand magnetism. The teacher can do this by guiding the hands-on activities in such a way as to build up this understanding. From a discourse perspective, this involves moving the students from the discourse around action to specific reflection discourse and to general reflection. This is done by engaging the students in reflection on the experiments, during which time taxonomies and causal relations are built up and generalizations are made.

In Mrs. Montgomery's class, the teacher had the students carry out experiments, and she systematically built up new taxonomies and causal relations through dialogue with the students. With each experiment, she brought the students beyond their context-dependent action discourse by eliciting specific reflection, typically in the form of recounts. She did this by gathering the students at the front of the classroom, away from the equipment, and asking them questions such as *what did you do?* and *what happened?* From this, she focused on what was common among the students' findings, moving from the specific reflections they offered to general reflections, and at the same time building and reinforcing taxonomies and causal relations. Table 8.2 illustrates this social practice, using discourse data from Experiment 10, an experiment which applied the "rule of magnetism" that the students had learned in the previous class to show that ring magnets, like other magnets, have two poles, even though these are not marked on the magnets. In other words, the experiment used the rule of magnetism to explain what was happening with the ring magnets.

**Table 8.2: Action and reflection discourse in Mrs. Montgomery's class**

| Social practice | Content/Action | Discourse | Examples |
|---|---|---|---|
| theory | (understanding) magnetism | general reflection discourse | What is the rule? North and south always attract.<br>What repels? North and north or south and south. |
| | | specific reflection discourse | So… what happened here? It repelled.<br>So if it's attracting, what is underneath here? |
| practice | doing experiments with magnets | action discourse | This is cool!<br>I'm going to test this. Watch this.<br>It jumps up.<br>It's floating. It's floating. It's so funny. |

The distinction between action discourse and specific reflection discourse is not always clear. In the example from Table 8.2 above, the students reflected on what they were experiencing by observing "it jumps up" and "it's floating," whereas they responded to the teacher's questions by saying "it repelled." What made the specific reflection discourse different from the action discourse was Mrs. Montgomery's use of questioning, which connected the students' hands-on experimentation to the more scientific taxonomies and causal reasoning the teacher was trying to build. Mrs. Montgomery used the students' hands-on experiences and language to translate between their current understanding and the new concepts, thereby acknowledging their everyday "reflection-in-action" discourse, but then systematically guided the reflection, insisting on the use of correct terminology during this reflection. This systematic construction marked a major difference between the students' action discourse and the teacher's guided reflection.

Mrs. Montgomery shifted between specific reflection and general reflection, connecting what the students found from carrying out their experiments (the guided specific reflection dialogues) to the more general theory of magnetism. The shift did not typically involve a single move from specific to general reflection, but went back and forth between what the students had experienced and the general theory the teacher was trying to teach. Table 8.3 shows how the teacher slowly and carefully constructed knowledge about the ring magnets, making connections between what the students had already learned about magnetism and how this previous knowledge applied to the present case. Moreover, the movement between the specific and the general reflection discourse offered the students opportunities to talk about what they were learning, thereby practicing their science English.

**Table 8.3: Specific and general reflection in Mrs. Montgomery's class**

| Speaker | Specific reflection | General reflection | Other |
|---|---|---|---|
| Teacher | | | Boys and girls |
| | look carefully at the diagram. What does our first diagram look like? Or what does one diagram look like? Do they both look like this? | | |
| Students | No. | | |
| Teacher | No. What do they look like? Walter? | | |
| Walter | North and south. | | |
| Teacher | That's right. So... what happened here? | | |
| Students | It repelled. | | |
| Teacher | They're repelling. Right. They were repelling and I'm going to turn this one over. What do we call this? North or south? | | |

Table 8.3 *(continued)*

| Speaker | Specific reflection | General reflection | Other |
|---|---|---|---|
| Students | North. | | |
| Teacher | North. I'm turning it over. What... | It doesn't matter. | |
| Students | Attract. | | |
| Teacher | So if it's attracting what is underneath here? North or south? | | |
| Students | South. | | |
| Teacher | South. Right. The bottom is probably north and this part is south. This could be north. This could be south. This could be north or this could be south. | Does it matter? No it doesn't. Why? Because? | |
| Students | | Because north and south. | |
| Teacher | | Because north and south and what do north and south always do? What is the rule? | |
| Students | | Attracts. | |
| Teacher | That's right. | North and south always attract. What repels? | |
| Students | | North and north or south and south. | |
| Teacher | Yup. | North north. That's repel. | |
| Student | | South and south repel? | |
| Teacher | So these two could be either what? | North and north repel. So north and north repel and south and south repel. | |
| Student | North and north. | | |
| Teacher | North and north or south and south. You're right. | What do we know for sure that one is going to be? | |
| Student | | North. | |
| Teacher | | And one is going to be? | |
| Student | | South. | |
| Teacher | Right. Okay. So tell me about these magnets. Do they have a north and a south? | South. | |
| Students | Yeah. | | |
| Teacher | Is it on the same side? | | |
| Student | No. | | |

**Table 8.3** ***(continued)***

| Speaker | Specific reflection | General reflection | Other |
|---|---|---|---|
| Teacher | No? Who says they're different? *(Show of hands.)* If this side is north... if this side of the ring magnet is north what is the other side of it? | | |
| Student | South. | | |
| Teacher | | So the ring magnet has a north and south? | |
| Students | | Yes. | |
| Teacher | | How do we know? | |
| Jack | Because we tried it out. | | |
| Teacher | And? What did we discover? | | |
| Students | | Magnets attract. | |
| Teacher | | | Let Jack finish. |
| Jack | | Because if you turn it around it won't attract and if you turn it around it'll attract. | |
| Teacher | | So it has a north and south? Yes it does. And is it all on the same side of the magnet? | |
| Jack | | No. | |
| Teacher | | No. One side of the magnet will be? | |
| Jack | | North. | |
| Teacher | | And the other side of the magnet will be? | |
| Students | | South. | |
| Teacher | | Right. And when we have two souths coming together they are going to? | |
| Student | | Um repel. | |
| Teacher | | Repel. If we have norths coming together they are going to? | |
| Student | | Repel. | |
| Teacher | | If we have a north and a south coming together they're going to? | |
| Student | | Attract. | |
| Teacher | | Attract. Just like the other magnets. | |

After leading the students to the conclusion that the ring magnets were no different than the other magnets they had worked with, Mrs. Montgomery went back to the topic of the diagrams, making sure that the students had drawn them correctly (specific reflection on the experiments), then asked what the conclusions were for the experiment (general reflection). The students responded that they could show that the invisible force was real by showing how the north and south poles on the magnets repel and attract.

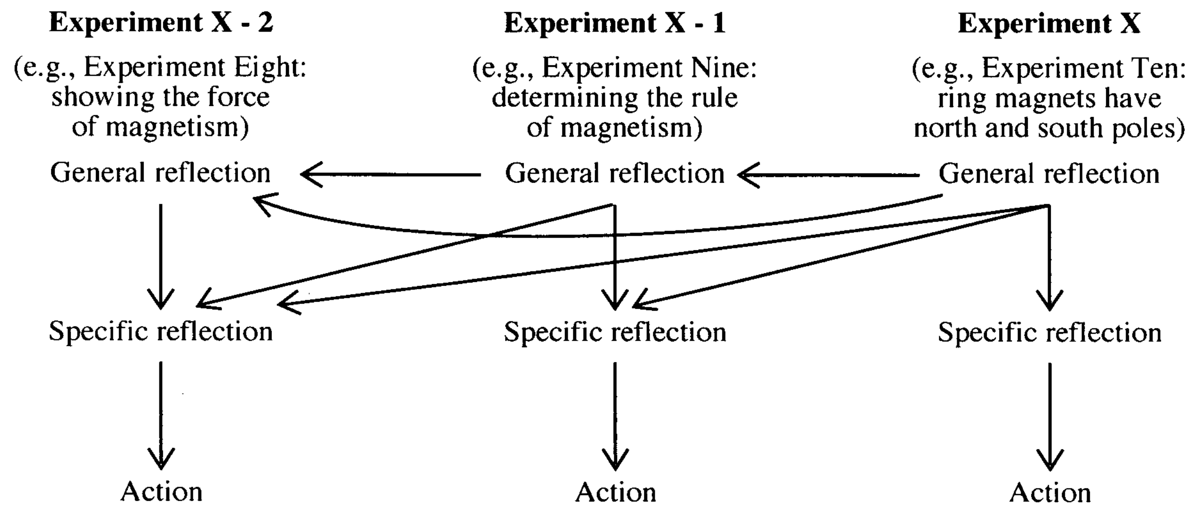
Jack's explanation for how the class could tell that a ring magnet has a north pole and a south pole is a good example of how an understanding of magnetism was set up by Mrs. Montgomery. She had carefully built up the taxonomy for north and south poles as well as for repel and attract, and Jack used these in the causal sequences he constructed:

> Because if you turn it around it won't attract and if you turn it around it'll attract.

In other words, Jack explained that turning the magnets around to have various poles facing each other would cause attraction or repulsion, depending on the poles which were together. His explanation showed that he understood the causal relations Mrs. Montgomery had been introducing to the students.

The data in Table 8.3 show that Mrs. Montgomery deliberately had the students reflect on previous experiments to help them understand their current findings. The students had learned the rule of magnetism in their previous class and were expected to reflect on it, to use it to explain what they saw happening in Experiment Ten. In fact, when the teacher asked for evidence that the ring magnets had a north and a south pole ("How do we know?"), she was trying to elicit the students' general reflection about the rule of magnetism. Instead, though, Jack responded that they had done an experiment ("Because we tried it out."), which brought the reflection back to the specific ("And what did we discover?") before becoming general once more. Mrs. Montgomery had organized the unit in such a way that this general reflection discourse could be built from the specifics of the current day's work or any of the previous experiments, or from the general understandings of previous classes, as Figure 8.1 attempts to illustrate.

**Figure 8.1: Connections among experiments, specific, and general discourse**




To sum up, Mrs. Montgomery used the students' action discourse to help translate their everyday understandings into science concepts, thereby building new taxonomies. Her ordering of the experiments and her questioning provided opportunities for systematic reflection which moved between specific and general, building taxonomies and causal reasoning, and giving students opportunities to explain their evolving understanding. The teacher also had students reflect on previous experiments as they related to their new understandings of magnetism. Her strategies helped the students connect their hands-on practice with the theory of magnetism, as shown through the discourse of the interactions.

In Mrs. Sinclair's class, most of the time spent on the unit involved the children carrying out the experiments and completing their magnet booklets. The teacher, unable to pull the students away from their experiments to discuss their findings because each pair was working on different experiments each day, instead joined the action at the stations, primarily offering help with directions so that the students could complete the tasks as instructed. When she was not offering directions, her discourse frequently resembled the students' comments. At Station Two, for example, where the students did the same experiment with the "floating" ring magnets as discussed above, Mrs. Sinclair's discourse matched the students' action discourse, and the only contribution to general reflection was a request for the student to state what he had written in his magnet booklet to complete the sentence "I can show the invisible forces of magnetism are real by...." Table 8.4 illustrates the types of discourse using data from Station Two.

**Table 8.4: Action and reflection discourse in Mrs. Sinclair's class**

| Social practice | Content/Action | Discourse | Examples |
|---|---|---|---|
| theory | (understanding) magnetism | general reflection discourse | Stanley: By showing my diagram.<br>Teacher: Yeah. Or by showing it in an experiment. |
| | | specific reflection discourse | Teacher: Isn't that nifty? I just got a bang out of this experiment. It's neat. |
| practice | doing experiments with magnets | action discourse | Mandy: This is cool! Lookit! We're magic!<br>Stanley: Watch this watch this watch this! Um... flip this over. Now try it... Put it in the same way. Now put it that way now. Wow. Lookit my magic! Wow! Lookit!<br>Mandy: It's pushing! This is cool! |

Mrs. Sinclair's comment about the experiment was not different from Stanley's and Mandy's action discourse:

Teacher: Isn't that nifty?
It's neat.
Mandy: This is cool!
Stanley: Wow. Lookit!

There is little here to offer a bridge between what the students are seeing and talking about in their everyday language, and what their conclusions, or general reflections, should be.

After the students had manipulated the equipment for a while, Mrs. Sinclair asked them what their conclusions were, drawing out their general reflections or understandings of magnetism from the experiment. Stanley stated that he could show that the invisible force of magnetism was real "by showing my diagram." Mrs. Sinclair accepted this but also presented an alternative ("Or by showing it in an experiment"), which was rejected by Stanley. Yet showing a diagram does not offer evidence of the force of magnetism, and nor does the response offer evidence that Stanley has understood what was happening with the two ring magnets. In other words, no connections appear to have been made between the rule of magnetism and what has happened in the experiment at Station Two. There has been no connection between practice and theory, no systematic reflection on the action for these students at this station. The discourse has been primarily action.

**Table 8.5: Specific and general reflection in Mrs. Sinclair's class**

| Speaker | Specific reflection | General reflection | Other |
|---|---|---|---|
| Brian | This doesn't make sense. It says… | | Mrs Sinclair? |
| Teacher | | | Okay? |
| Brian | one north pole. One south pole. | | |
| Teacher | Okay so that means one of these and one of these. These ones– We call these both south if you want. They push apart. These push apart right? | But if you mix them what happens? What's the word? | |
| Brian | | Attract. | |
| Teacher | That's right. | They attract. So one north and one south pole attract. | |
| Brian | So I just write "they attract"? | | |
| Teacher | Yeah. And then down below when it comes to the rule you can put either Right? | north and north poles attract or south and south poles att– no they don't attract. North and south poles attract. | |
| Brian | Yeah. | | |
| Teacher | Right? | But north and north poles repel or push apart. Or south and south poles repel. | |
| Brian | Okay. | | |
| Teacher | Okay? Good. | | |

Even at stations where there is an effort being made to provide more guidance, Mrs. Sinclair typically seemed to be directing the students towards completion of the tasks rather than making connections between the hands-on doing of the experiments and an understanding of magnetism. To illustrate this, Table 8.5 displays a dialogue between Brian and Mrs. Sinclair in which Brian has asked for help to understand what he was supposed to do to discover the rule of magnetism. Brian's part in the dialogue was small. After he pointed out his area of difficulty, the teacher gave him the answers rather than helping him to construct his own understanding. In other words, there was no systematic building up of understanding by the teacher. Perhaps he had indeed understood the rule of magnetism, but there was no evidence at the end of this dialogue that Brian had linked practice to theory; he simply wrote down what he was told to and responded with "okay."

As Chapter 4 described, Mrs. Sinclair involved her students in an initial discussion to present the key vocabulary that they would need to complete the experiments at the stations, but she did not systematically build up the concepts as the students worked and nor did she attempt to reinforce the vocabulary she had presented. In other words, while the teacher had attempted to connect the new vocabulary to the students' background knowledge during the initial class, she had difficulty connecting the students' current hands-on experiences with new theory primarily because of the way the students moved through the stations. With students working on different experiments in a different order, experiments which took different times to complete and which required reading different amounts of instructions—and with differing levels of reading proficiency in the class—the discourse suggested that the teacher spent more time directing and managing the experiments to keep all the students working in an orderly fashion than she did helping them understand magnetism. With few exceptions, she either gave the students the answers or accepted the ones they offered. New taxonomies were rarely constructed; the students primarily used the language they had brought with them, and Mrs. Sinclair was not able to help each group of students at each station move from their specific reflection-in-action discourse to general discourse. She instead supplied the general reflection discourse for them when they were unable to do so themselves.

### 8.1.2 The high school classes

Whereas in the primary school science classes, the unit revolved around the experiential aspects of hands-on experimentation within the narrow topic of magnetism, the high school classes were taught using a textbook and lecture orientation. There were fewer lab activities to support the broader topic of matter, and the teacher relied much more on using language—oral and written text—to construct knowledge with and for the students. Just as various concepts needed to be introduced to the younger students and built up in order for them to understand magnetism, the older students were presented with concepts such as *physical properties* and *mixtures* in order to build up an understanding of matter. This social practice for the older classes is captured in Table 8.6.

**Table 8.6: The social practice of learning about matter**

| Social practice | Content/Action | Discourse |
|---|---|---|
| theory | (understanding) matter | general reflection discourse<br>reading about matter<br>classroom discussion |
| | | specific reflection discourse |
| practice | • doing experiments about matter | action discourse |

In Mr. Peterson's class, the teacher had the students do three lab activities. As Chapter 6 discussed, the students' discourse during the labs was primarily observational or procedural, with occasional efforts to explain when they needed to problem solve to fill in charts for their lab reports. As the students neared completion of the labs, Mr. Peterson asked questions about what they had found, directing these questions towards the general theory that he was attempting to teach. Table 8.7 shows examples of the discourse around one experiment which investigated differences between physical and chemical changes.

**Table 8.7: Action and reflection discourse in Mr. Peterson's class**

| Social practice | Content/Action | Discourse | Examples |
|---|---|---|---|
| theory | (understanding) matter | general reflection discourse | A color change is one of the clues to indicate what? What if heat's released? Gas produced? Chemical. |
| | | specific reflection discourse | Did it change color at all when you added the water? It went to blue. When you added a few drops of water did anybody notice that it got warmer? |
| practice | doing experiments with matter | action discourse | It is uh kind of silver or smoke. What color is this kind? It turns pink. |

Mr. Peterson also offered five major demonstrations for the students as well as several small demonstrations which he used to give the students visual experiences to support the concepts he was teaching. The discourse during these interactions was controlled by the teacher and frequently included either comments about what he was doing in rather a play-by-play monologue, or questions to elicit predictions or confirmation from the students. The teacher's discourse during these demonstrations was systematic specific reflection about what he was doing, which he shifted to general reflection as he progressed through the topic. Table 8.8 shows two examples of this shift from specific to general during Mr. Peterson's mini-demonstrations. In both of these examples, Mr. Peterson grounded the specific reflection in the visible context and moved from this to construct a more general understanding. The teacher also provided causal connections as he moved to general reflection. In the first example, he concluded that the physical property of color "helps you tell" the difference, offering color as the agent which causes one to determine differences. In the second example, he suggested that density determines sinking and floating. Both examples highlight the causal relations which concern the physical properties he is attempting to teach.

**Table 8.8: Shifting from specific to general in Mr. Peterson's demonstrations**

| Speaker | Specific reflection | General reflection | Other |
|---|---|---|---|
| Teacher | | | So for example. Start you off really easily here. |
| | I've got... two containers here... this one... and this one... Okay? So what do you think? Do you think these are the same substances in these containers... | | |
| Students | No. | | |
| Teacher | or different. | | |
| Students | Different. | | |
| Teacher | How do you know? | | |
| Student | Because they're different colors. | | |
| Teacher | There you go. | So color's probably the most obvious first physical property that helps you tell. | |
| Teacher | Here's—here's a rubber stopper in water. *(Drops in it.)* | | |
| Students | Whoa! | | |
| Teacher | | Rubber's more dense than water. | |
| | Here's cork in water. *(Drops it in.)* | | |
| Male: | Less. | | |
| Male | Wow. | | |
| Female | Cool! | | |
| Teacher | It floats quite high right? | | |
| Students | Yes. | | |
| Female | It's so cool. | | |
| Teacher | Okay. | It would float lower right? Cork's around point two five. About a quarter as dense as water... Now... why things sink or float in water is dependent on density. | |

Whereas the labs and demonstrations offered visible contexts for specific reflection which can then be used to construct generalizations, much of Mr. Peterson's class revolved around talk alone. As noted in Chapter 6, Mr. Peterson typically involved the students in discussions by presenting scenarios and asking the students questions which probed their background knowledge and experience. His talk in those situations can be considered specific reflection in that it was often similar to the discourse around the action of the demonstrations. In fact, these scenarios resembled verbal experiments or experiments carried out in the imagination. For example, in Table 8.9, Mr. Peterson noted "I've got water and I've got alcohol," but he had neither in front of him; he was creating the context linguistically for the students to imagine. Table 8.9 shows how the teacher moved from the specific reflection or scenarios and past experience to general reflection.

**Table 8.9: Reflection on talk**

| Speaker | Specific reflection | General reflection | Other |
|---|---|---|---|
| Teacher | I've got some water here well I've got water and I've got alcohol and I'm not telling you which one is which... How would you tell the difference? | | |
| Students | Smell. | | |
| Teacher | There you go. | There's another physical property. See water and alcohol you can't tell the difference between them by looking at them. But... smell will do it. | |
| Teacher | Now who's noticed that— and guys... you might not want to put your hand up here. You know what I'm saying? *(Laughter.)* What does that mean? Ladies? Maybe? Or maybe you've seen your sister or mother or whatever. But have you noticed that nail polish remover evaporates very quickly? Does it feel cool when you get it on your finger? | | |
| Student | It dries out my skin. | | |
| Teacher | It dries out your skin. Yeah. That would. | So some substances evaporate faster than others. And that is related to another physical property actually. | |

As can be seen in all the examples above, Mr. Peterson moved systematically from specific reflection—whether on the present action of labs and demonstrations or on past actions (experience) which were often in the form of imagined scenarios—to general reflection, and in the process he helped the students build up their understanding of matter by constructing taxonomies and causal relations. His lessons were generally very teacher centered, but through questioning as well as visual (experiential) contexts, he involved the students in this construction, linking the science they were studying to the understanding many of them already had.

**Table 8.10: Ms. Armstrong's guided recount of the lab**

| Speaker | Specific reflection | General reflection | Other |
|---|---|---|---|
| Teacher | | What does material mean? | |
| Male | | What do we use. | |
| Teacher | What did we use? And what did we use? | | |
| Male | Three large test tubes. | | |
| Rhonda | Chromatography paper. | | |
| | *(Several turns later.)* | | |
| Teacher | | What is after procedures? | |
| Male | | Observations. | |
| Teacher | | Observation. Good. What does observation mean? | |
| Male | What you saw. | | |
| Teacher | What you saw. Exactly. And what did we see? | | |
| Rick | See the color… changed. | | |
| Teacher | Okay we saw the colors— | | |
| Rick | Spread out. | | |
| Teacher | change but… before we saw the color change what did we see happen?… Before the colors changed? What happened right at the beginning? | | |

In Ms. Armstrong's class, two labs experiments were carried out as well as one observation activity, but as mentioned in Chapter 7, the language used by the students during these activities was typically their first language rather than English. The specific reflection which Ms. Armstrong directed concerned recounts of the experiments and was aimed at helping the students write up their lab reports. The shift to general reflection was marked by the teacher's questions about the conclusions the students had reached about the lab, as Table 8.10 shows. This oral recounting of the experiment and the findings continued for several minutes before the teacher asked the students to work in groups to summarize their findings in writing. She moved around from group to group, reading what they wrote and connecting on its grammatical accuracy as well as the completeness of the content. All this was done as specific reflection on the lab results and the writing as the students worked on summarizing their observations. The teacher then moved from observations to conclusions, which moved the discourse from the specific reflection characteristic of Table 8.10 to the general reflection touched upon in Table 8.11. This general reflection was done for students to complete their lab reports.

**Table 8.11: General reflection as conclusion**

| Speaker | Specific reflection | General reflection | Other |
|---|---|---|---|
| Teacher | From our observations... from our data table... Okay? From this? Which ones of these colors are mixtures and which ones are pure colors? Which are mixtures first of all? | | |
| Male | Yellow. | | |
| Students | Yellow and green and purple. | | |
| Fred | Oh oh oh! Green and purple! | | |
| Teacher | | Green and purple are mixtures. Yellow red and blue are... pure colors. And how do we know? | |
| Fred | Because purple and green separated. | | |
| Teacher | Okay. Purple and green separated... and blue did not. Or yellow did not. Okay? Your conclusion is actually fairly simple. | | |

The two labs which the students did offered contexts which could be used to link specific reflection (what the students experienced) with more general theory in science. As noted in Chapter 7, however, the conclusions of the chromatography lab—that certain colors were mixtures because they separated—did not fully match the general reflection discourse which the teacher was trying to present, that mixtures do not change their physical properties. Specific reflection also occurred when the teacher was correcting what the students had written on the blackboard as she asked whether what had been written was okay grammatically, mechanically, and for content. These dialogues typically remained as specific dialogues as they focused on what was on the board.

Much of the discourse which occurred in the class was not about the students' actions or experience. As Chapter 7 described, it typically revolved around theory as presented in the text or handouts, and introduced by the teacher or read aloud by the students at the teacher's request. In other words, the dialogue was largely general reflection as theory was presented and questions drilled the students on their understanding of it, as Table 8.12 shows. This type of discourse, with its general reflection quality, is also typical of the type of questioning which Ms. Armstrong used to find out about students' schedules and characteristics, which she used to contrast with the scientific taxonomies she was attempting to teach, as Chapter 7 discussed. For example, she contrasted the characteristics of Cory ("male, noisy, bad, short," and so on) with the characteristics of particular families on the periodic table. Both were stated as general reflections, or truths.

As this discussion illustrates, much of the discourse in Ms. Armstrong's class was general reflection, with the teacher frequently repeating and drilling the theory throughout the unit. Much of this theory revolved around defining terms. The questions she asked rarely probed the students' own experiences, and specific reflection typically occurred only during recounts of the lab experiments or in discussion about the mechanical correctness of what the students had written on the board. In other words, rather than systematically moving between the students' action or specific reflection discourse and general reflection, Ms. Armstrong usually attempted to teach understanding from the theory, simplifying the language whenever possible or contrasting it with everyday general "truths" to help the students understand.

**Table 8.12: Reflection on the text as action**

| Speaker | Specific reflection | General reflection | Other |
|---|---|---|---|
| Teacher | | *(Reading from text.)* "Water is usually seen as a liquid. It is clear. It mixes with many things easily." Okay so it's easy to make a mixture with water. So if you add coffee what do you get? | |
| Male | | Coffee. | |
| Teacher | | You get a drink called coffee. Okay. If you mix it with salt? If you put salt in the water does that mix easily? No? | |
| Male | | Yes. | |
| Teacher | | Yes. It does. What about sugar? | |
| Male | | Yes. | |
| Teacher | | You put sugar in water it will dissolve. Okay it will mix easily. All right. *(Continues reading.)* | |

### 8.1.3 Similarities and differences

Regarding social practice theory, it can be seen through the discourse examples presented in the preceding section that each teacher approached the teaching and learning of science in a somewhat different way. Figure 8.2 illustrates these differences, and this section discusses them, along with the similarities.

**Figure 8.2: Social practice and the four teaching styles**

| Social practice | Discourse | Learning and teaching | Montgomery | Sinclair | Peterson | Armstrong |
|---|---|---|---|---|---|---|
| Theory | Reflection | Expository learning (lectures, textbooks, seminars) | To theory | | From theory | Theory |
| Practice | Action | Experiential learning (labs, fieldwork, the world) | From practice | Practice | To practice | |

Mrs. Montgomery's and Mr. Peterson's classes were similar in several notable ways. Both teachers frequently asked questions about specifics of the action which either the students had just done or had experienced in their past, and then moved between these specifics and the more general theory of the topic. During these moves, both teachers constructed new taxonomies or causal relations. Discursively, both moved back and forth between the specific and the general to reinforce the new concepts and to make connections to other concepts or taxonomies within the same topic. This systematic reflection went together with a systematic presentation of topics so that the concepts could be built up slowly using interlocking definitions when needed.

Mrs. Sinclair's class differed from Mrs. Montgomery's and Mr. Peterson's in that the discourse remained primarily anchored in the action of the experiments. Specific reflection was either participants' observations of what was happening, typically uttered in everyday language, or was Mrs. Sinclair's directing of the action to make sure students were continuing on task. General reflection appeared when the conclusions to the experiments needed to be determined, and frequently this involved Mrs. Sinclair offering the answers for the students, rather than using questioning to move systematically towards general reflection. With pairs of students working on different experiments at different times, Mrs. Sinclair had her hands full directing the tasks and responding to the students' questions, and systematic movement from practice to theory was therefore a challenge that was difficult to meet.

Whereas Mrs. Sinclair's class usually used action and specific reflection dialogue, the participants in Ms. Armstrong's class used general reflection discourse except for occasions when the teacher recounted the lab procedures and findings or focused on correcting the students' written board work. During the group work, when action discourse occurred, the students talked in their first languages or not at all, and during these times, Ms. Armstrong, like Mrs. Sinclair, focused on making sure the students were on task, often examining the written text they were producing as they worked. Although Ms. Armstrong made an effort to cover the textbook content in a systematic way, there was little movement during these lessons between the information which was grounded in the students' experience (specific reflection) and the new taxonomies and causal relations which Ms. Armstrong was attempting to construct. In other words, there was little systematic movement between practice and theory as there was in Mrs. Montgomery's and Mr. Peterson's classes.

Mr. Peterson's class differed from Mrs. Montgomery's in two interconnected ways. First, his included many more concepts than did the younger students' topic which meant that he needed either to build up more taxonomies and causal relations, or to ensure that the students had already built up these concepts prior to his lesson. Second, his class was much more teacher-centered and lecture-based, depending mostly on heavily teacher-led lessons where the knowledge was frequently constructed through language rather than through the physical classroom experience which Mrs. Montgomery's students enjoyed. This lecture-based approach assumed that the students had a sufficient knowledge base to understand what the teacher was presenting and on which new knowledge could be constructed. In contrast, the student-centered, experiential approach which Mrs. Montgomery employed did not make this assumption; instead, the hands-on experiments provided the basis for knowledge construction. To capture the differences between the two classes, therefore, one can consider that whereas Mrs. Montgomery anchored her lessons in experience and moved back and forth between the specific reflection on this experience and the general reflection she was attempting to teach, Mr. Peterson's lessons were based much more on lectures. This greater use of lectures at the higher grade levels is not surprising; the 1991 British Columbia assessment of science (Bateson et al., 1992) reported that high school science teachers used lectures and text-based approaches more frequently than did elementary school teachers.

### 8.1.4 Summary of research question one

In sum, all classes contained episodes of practical experience and episodes where scientific theories and concepts were discussed and causal explanations were constructed. At the grade two level, both teachers began by engaging students in experiments and at some point in discussions of concepts and theories. Mrs. Sinclair's group stayed mainly at the practical and experiential level. When Mrs. Sinclair moved to general reflection, she offered answers for her students rather than using questions to help them move systematically towards general reflection. Mrs. Montgomery, on the other hand, was able to move systematically towards general reflection. Her students were then able to generalize from their experience and to construct and express the taxonomies and causal sequences relevant to the topic of magnetism.

In the high school classes, the teachers began with concepts and theory. Ms. Armstrong stayed primarily at this level, using the textbook as her anchor and rarely bridging the theory to the students' experiences in or out of class. Mr. Peterson, however, brought the students' experiences into the discussion, linking them to the theory he was presenting.

It appeared that Mrs. Montgomery and Mr. Peterson made systematic connections between practical experience and general reflection and were able to help their students move between theory and practice, reflection and experience, and express an understanding of relevant taxonomies and causal explanations, while Mrs. Sinclair and Ms. Armstrong did not make this link.

### 8.2 Responding to research question two

As shown in all four data presentation chapters, the speakers used various language features to construct explanations of the topics they were studying. In the primary classes, the students offered a wealth of language as they interacted with each other and with their respective teachers. In the high school classes, however, the lessons were heavily teacher-centered, and consequently little extended discourse by the students was available to analyze for the linguistic features of causal explanations. For this reason, as noted in Chapter 3, research question two makes use of interviews, during which time the students in all four contexts were given many opportunities to talk about what they were learning. In this section of the chapter, the findings from the four interview contexts will be summarized and presented side by side to reveal the patterns which have emerged. Because the interviews varied in corpus size, the frequency charts offered in this chapter will be averaged to tokens per 1000 words, as discussed in Chapter 3, Section 3.5.2.

The section will be divided into five main areas, with the first one addressing the resources which the students used to construct causal explanations in the interviews. Section 8.2.2 will examine the causal features of the mainstream English speakers in the primary and high school classes, looking at the developmental path of cause between these groups.

Section 8.2.3 will also discuss the developmental path of cause, but with the ESL and mainstream classes (at both age levels) in comparison. Section 8.2.4 will address the use of the negative as a resource for meaning, and the final section will finish with a summary of the findings for research question two.

### 8.2.1 Summarizing the features of causal discourse used

The section will be divided into six main areas: conjunctions, circumstances, processes, participants, lexical density, and the use of the negative in causal and temporal relations. Each topic will summarize the use of the feature by the students across the interviews of the four contexts. It will provide the basic information needed both to hold the data up to the studies by Veel (1997) and Mohan et al. (2002), and to introduce new topics for discussion. It should be noted that quality (adjectives), although used by the students, did not surface as causal or temporal in the discourse data of any of the contexts and is therefore not discussed here beyond stating that the high school students in general used a greater number of technical qualities, such as *ionic* and *reactive,* than did the primary students.

As the following sub-sections will show, the students used various causal and temporal language features to construct their explanations, with the students in different contexts preferring certain features over others to do so. Generally speaking, the use of resources to construct discourse internally was rare; the explanations were typically more external, suggesting that the students in all groups were more concerned with explaining what they considered to be reality than with the textual organization of their arguments. Overall, the numbers suggest that the older students were able to make greater use of the more grammatically metaphoric resources, and the older mainstream students were the most proficient with these of all groups.

#### 8.2.1.1 The use of causal and temporal conjunctions

As Table 8.13 shows, speakers in all four contexts made use of both temporal and causal conjunctions in their explanations, but whereas the primary mainstream class and the high school ESL class favored causal over temporal conjunctions, the primary ESL and the high school mainstream groups preferred the opposite. The high school mainstream had the most noticeable difference, preferring temporal over causal conjunctions 51.11 to 13.09. If the two age groups—primary and high school—are combined and examined, it can be seen that the older students in general used the temporal conjunctions (total=80.79) more often than the younger students (total=58.94), and the younger students used more causal conjunctions (total=58.38) than did the older students (total=43.93). Looking at the ESL contexts compared to the mainstream students, it can be seen that the two mainstream groups together used 76.46 temporal conjunctions out of 1000 words compared to the 63.27 temporal conjunctions used by the ESL students. In contrast, the ESL students used more causal conjunctions (57.20) compared to the mainstream students (45.01).

**Table 8.13: Conjunctions used in the four contexts**

| | Primary ESL | Primary MS | High school ESL | High school MS |
|---|---|---|---|---|
| temporal conjunctions (external) | 33.59 | 25.35 | 29.68 | 51.11 |
| temporal conjunctions (internal) | 0 | 0 | 0 | 0 |
| consequential conjunctions (external) | 26.46 | 31.92 | 30.53 | 12.81 |
| consequential conjunctions (internal) | 0 | 0 | 0 | .28 |

The most common temporal and causal conjunctions varied among the four contexts, as Table 8.14 shows. The primary students' top three choices were similar: the causal conjunctions *because* and *if* and the temporal conjunction *when.* The primary ESL students favored *because,* followed by *if* and *when,* and the primary mainstream students used *if* the most often, followed by *because* and *when.* In contrast, the high school students' choices reflected a great diversity. Whereas the most common conjunction for the ESL students was the causal conjunction *so* followed by temporal *and* and *when,* the mainstream students favored *and then,* followed by *and* and *then,* reflecting their overall preference for temporal conjunctions.

**Table 8.14: The most popular conjunctions used in the four contexts**

| | Primary ESL | Primary MS | High school ESL | High school MS |
|---|---|---|---|---|
| and | 6.62 | 6.57 | 10.53 | 13.09 |
| and then | 7.63 | 2.82 | 2.74 | 15.6 |
| then | 6.11 | 1.88 | 3.79 | 8.64 |
| when | 10.18 | 7.51 | 9.68 | 5.57 |
| because | 13.74 | 14.08 | 4.42 | 4.18 |
| so | 1.53 | 2.82 | 19.16 | 4.04 |
| if | 11.2 | 15.02 | 5.47 | 1.95 |

#### 8.2.1.2 The use of circumstances

As well as conjunctions, the speakers in all four contexts used various circumstances to construct their explanations. As Table 8.15 shows, circumstances of place, which are usually associated with temporal or sequential explanations, were the most common for all four groups. In fact, the two types of circumstances associated with time—circumstances of time and place—were used by all groups more often than the two kinds of causal circumstances, those of cause and means. Temporal circumstances such as *at first, in summer, in the beginning,* and *after the reaction* were used more often by the older students (6.51) than the younger students (.5), and were not used at all by the primary mainstream group. Causal circumstances such as *because of* and *for some reason* were favored by the younger students (2.38) more than by the older ones (.21), with the high school mainstream not using any. Circumstances of means, such as *by the chemical change* or *with the hammer,* were used almost equally by younger (1.88) and older (1.82) students, although the primary ESL students did not utter circumstances of means at all.

If the ESL students are compared to the mainstream students in this study, it can be seen that the mainstream students use more circumstances of cause and means (4.32) than the ESL students (1.97), who use more circumstances of time and place (48.61) than the mainstream students (38.52).

**Table 8.15: The circumstances used in the four contexts**

| | Primary ESL | Primary MS | High school ESL | High school MS |
|---|---|---|---|---|
| circumstances of cause | 0.5 | 1.88 | 0.21 | 0 |
| circumstances of means | 0 | 1.88 | 1.26 | 0.56 |
| circumstances of time | 0.5 | 0 | 4.84 | 1.67 |
| circumstances of place | 17.8 | 15.96 | 25.47 | 20.89 |

### 8.2.1.3 The use of processes

The high school mainstream students used more temporal and causal processes than any of the other three groups, as Table 8.16 indicates. The high school ESL students made use of causal processes as well, although as shown in chapter five, they used only three causal processes with *make* being the most common. *Make* was the only causal process used by the primary students; causal processes in general were used much less often at the younger grades than at the upper grades. Temporal processes were not used by the high school ESL students nor by any of the primary students. Processes of evidence, in the discourse data as *prove* and *show,* were used infrequently. The primary ESL students used *show* on one occasion (.51), just as the primary mainstream students used *prove* on one occasion (.94). The high school ESL students used no processes of evidence, but their mainstream counterparts used both *prove* and *show* a total of five times (.7).

**Table 8.16: The processes used in the four contexts**

| | Primary ESL | Primary MS | High school ESL | High school MS |
|---|---|---|---|---|
| causal processes | 2.4 | 1.88 | 4.21 | 6.41 |
| temporal processes | 0 | 0 | 0 | 1.39 |
| processes of evidence | .51 | .94 | 0 | .7 |

### 8.2.1.4 The use of participants

Entities can be examined from two angles: temporal and causal participants (e.g., *the first thing, the effect)*, and nominalizations and abstractions (e.g., *expansion, state).* Looking at causal participants, Table 8.17 indicates that these surfaced only in the discourse of the high school mainstream students. Temporal participants were also more frequent in the high school mainstream interviews, although they existed to some extent in the interview discourse of the high school ESL students (.42) and the primary mainstream students (.94).

**Table 8.17: Causal and temporal participants used in the four contexts**

| | Primary ESL | Primary MS | High school ESL | High school MS |
|---|---|---|---|---|
| temporal participants | 0 | .94 | .42 | 2.51 |
| causal participants | 0 | 0 | 0 | 4.46 |

Nominalizations, one form of grammatical metaphor, appeared as metaphoric processual entities, such as *reaction, evaporation,* and *bonding,* or as metaphoric quality entities, such as *heat* and *cold.* These were almost non-existent at the primary level, but appeared at the high school level where the mainstream students used more (21.22 tokens per 1000) than the ESL students (13.61), as Table 8.18 suggests. Surprisingly, when the terms are normalized to occurrences (tokens) per 1000, abstract technical terms, such as *north pole* or *atoms,* were used more often by the younger students (52.92) than by the older ones (12.56). Comparing mainstream to ESL students, the mainstream students used considerably fewer abstract technical terms (10.61) than did the ESL students (61.94). Concrete specialized entities were used marginally more by the younger students (50.17) than by the high school students (48.18). Looking at these entities from the perspective of ESL versus mainstream, it can been seen that the ESL students used more concrete specialized terms (60.69) than did the mainstream group (38.97).

**Table 8.18: Nominalizations, abstractions, and specialized terms**

| | Primary ESL | Primary MS | High school ESL | High school MS |
|---|---|---|---|---|
| metaphoric processual | 2.14 | 0 | 9.66 | 12.17 |
| metaphoric quality | 0 | 0 | 3.95 | 9.06 |
| abstract technical | 70.05 | 22.12 | 58.6 | 8.91 |
| concrete specialized | 56.15 | 39.42 | 62.56 | 38.9 |

As suggested by the students' processes and the entities used, and particularly the metaphoric entities and temporal and causal participants, it appears that the primary students depended on the more congruent ways to construct explanations, most notably conjunctions. At the high school level, as described in Chapter 7, the ESL students had trouble handling grammatical metaphor. Clear examples of this were Belinda's and Vicki's extension of *reaction* (a quality) to the role of participant ("they will have reactive") and process ("they'll reactive"), and Ken's search for the appropriate form of *explode* to construct a more metaphoric statement: "Put it into water and it doesn't make... isn't... it doesn't explode" (e.g., make an explosion, isn't explosive). In contrast to the ESL students' performance, the discourse of the mainstream students revealed an ease with this type of grammatical metaphor, as Chapter 6 discussed.

### 8.2.1.5 Lexical density

As Table 8.19 indicates, the lexical density of three out of the four contexts was similar, with the primary mainstream students showing a somewhat lower number (less dense) than the other three groups. These numbers appear to contradict to some extent what was noted in the preceding section about the younger students working more with conjunctions, and the high school mainstream students having a greater facility with nominalizations and higher numbers of processes: This should be reflected in a much greater lexical density for the high school mainstream speakers. It must be remembered, however, that the interview questions which the younger students were asked included classifications which were responded to with mostly lexical items, as the following example shows:

| | |
|---|---|
| Teacher: | What kinds of things do magnets attract? |
| Gary: | Metal. |
| Celeste: | Some money. |
| Shelly: | The type of metal that paper clips are made of. |
| Brian: | Paper clips. |

Moreover, the ESL students often responded with short answers which were not contained in full sentences:

| | |
|---|---|
| Researcher: | What way did it turn? |
| Aaron: | South. North. West. East. |
| Researcher: | What makes it turn around to face north? |
| Hannah: | The Earth. |

In contrast, the tasks for the older students involved more recount and explanation questions which demanded more use of grammar around the lexical items.

**Table 8.19: Lexical density across the four contexts**

| Primary ESL | Primary MS | High school ESL | High school MS |
|---|---|---|---|
| 39.5 | 35.3 | 39.8 | 39.2 |

The differences between the ESL and the mainstream students may also be related to the students' facility with grammar. Although all examples of pauses and false starts were taken out of the data prior to running the computer analysis, the grammar was not cleaned up. The data therefore contained sentences which needed grammatical items to make them complete. For example, in the following comment by Kevin, the hearer or reader needs to insert words in order to make the sentence more grammatical. Suggestions for these inserted words are in brackets:

Kevin: Chemical change is like [when you have] two or more elements.

There are also many examples of missing articles and auxiliary verbs in the speech of the ESL students which are present in the discourse of the native speakers. All of this can affect the results of a lexical density analysis on oral texts elicited from these groups using interview questions, and needs to be considered when interpreting the numbers above.

#### 8.2.1.6 The use of the negative in causal and temporal relations

Another point to mention when comparing the language of the four contexts is the use of negation in the construction of explanations. Table 8.20 shows the number of different negative relations as a percentage of the overall number of different causal and temporal relations constructed by each group. From this table, it can be seen that the younger students together (ESL + MS) used considerably more negative constructions than the older students considered together (26 out of 133, or 19.55%, compared to 37 out of 769, or 4.81%). It is also noticeable that the ESL students used more negative constructions than the mainstream students did (35 out of 372, or 9.41%, compared to 20 out of 501, or 3.99%). These findings suggest that both the younger students and the ESL students may have been using negation as a strategy in their meaning-making.

**Table 8.20: The use of negative causal and temporal relations**

| | Primary ESL | Primary MS | High school ESL | High school MS |
|---|---|---|---|---|
| negative / overall relations | 17/81 | 9/52 | 26/320 | 11/449 |
| % of negative relations | 20.99% | 17.31% | 8.13% | 2.45% |

### 8.2.2 The developmental path of cause: The mainstream English speakers

In Chapter 2, Section 2.7, Veel's idealized knowledge path (Veel, 1997) was described in detail. Here, Veel's basic hypotheses will be restated so that the data from this study can be discussed in light of them:

- Lexical density will increase.
- The number of nominalizations and abstractions will increase.
- Temporal conjunctions will decrease.
- Causal conjunctions will increase.
- External conjunctions will decrease.
- Internal conjunctions will increase.

Each hypothesis will be discussed in turn and the discussion will consider the move from the native English speakers in the mainstream primary class to the mainstream students in high school.

#### 8.2.2.1 Lexical density will increase

As shown in Table 8.19, the grade two mainstream students exhibited a lexical density of 35.3 whereas the grade nine students' discourse was calculated at 39.2. When the ESL students are examined, there is also an increase, but from 39.5 to 39.8, which is not as great. In general, though, these findings support Veel's hypothesis that lexical density will increase as the texts get "older." In the Mohan et al. (2002) study, the elementary text had a lexical density of 53.6, with the older text showing 56.3. The native-speaker oral discourse in the current study appears to be consistently about eighteen percent lower than the written text of Mohan et al., but both groups still show an increase over age groups. What is interesting, however, is that the ESL students at both age groups show a higher lexical density than their mainstream counterparts, but as Section 8.2.1.5 argued, there are issues involved in calculating lexical density in the types of oral interview tasks carried out in this study, and therefore further research is needed before definitive conclusions can be reached.

#### 8.2.2.2 Nominalizations and abstractions will increase

Veel's hypothesis stated that the knowledge path through school will be marked by an increase in frequency of nominalizations, which involve a move from the more congruent forms of expression to metaphorical ones, and abstractions, which also serve to move the text away from the here-and-now. The move towards nominalizations—and grammatical metaphor in general—was noted as well in the data presented by Mohan et al. (2002), who did not address abstract entities.

**Table 8.21: The path of nominalizations in the mainstream oral discourse**

| | Primary MS | High school MS |
|---|---|---|
| metaphoric processual entities | 0 | 13.23 |
| metaphoric quality entities | 0 | 3.76 |

Looking first at nominalizations, Table 8.21 shows that there were no examples of metaphoric processual entities or metaphoric quality entities at the primary school level, but they did occur in high school. This finding suggests that the older students were more adept at using nominalizations and handling grammatical metaphor than were the younger students, supporting Veel's hypothesis as well as Mohan et al.'s assertion that there is a shift towards more metaphorical constructions between the discourse of the younger students and that of the older ones. However, with regards to abstractions and concrete specialized (technical) terms, a different pattern emerges, as Table 8.22 indicates. Whereas there appear to be minimal differences in the frequencies of concrete specialized entities between the two age groups, the frequency of abstract technical terms decreased considerably in the older group. This reversal may be topic-specific, but it may also be the case that abstract terms can be acquired as single lexical items which do not involve movement between less and more congruent grammatical forms. It may also be the case that younger students use these words without fully understanding their meanings or how they related to the topic at hand. Abstract terms such as *gravity* and *electricity* and *war* were brought into the younger children's attempts to explain magnetism, regardless of their appropriateness, and these may have led to findings which were opposite to what Veel predicted.

**Table 8.22: The path of abstractions in the mainstream oral discourse**

| | Primary MS | High school MS |
|---|---|---|
| abstract technical entities | 21.6 | 12.67 |
| concrete specialized entities | 38.5 | 38.6 |

Another pair of entities should be taken into consideration. Temporal and causal participants play an important role in marking the general drift towards grammatical metaphor. Table 8.23 notes the differences between the younger and older students with regards to these entities, showing again that as the students age, they are able to make use of

**Table 8.23: The path of temporal and causal participants**

| | Primary MS | High school MS |
|---|---|---|
| temporal participants | .94 | 2.51 |
| causal participants | 0 | 4.46 |

more metaphoric constructions, offering evidence for a path which develops along the angle which Mohan et al. proposed.

In general then, an examination of the entities which the younger and older students used suggests a developmental movement towards the more metaphorical constructions. Further research would be needed before a similar claim could be made about a shift in abstract technical entities.

#### 8.2.2.3 Temporal conjunctions will decrease

Table 8.24 shows that the number of temporal conjunctions was not lower at the high school level. In fact, the data show that the number of external temporal relators more than doubled between the primary and high school levels. This may be attributed to the task design; whereas the younger students were asked questions such as *how do you know* and *why*, the older students were asked to talk about what they had seen or done and then generalize on their findings. This recount task may have led to the very high use of temporal/sequential relators.

**Table 8.24: The path of external temporal conjunctions**

| | Primary MS | High school MS |
|---|---|---|
| temporal conjunctions (external) | 25.35 | 51.11 |

#### 8.2.2.4 Causal conjunctions will increase

**Table 8.25: The path of external causal conjunctions**

| | Primary MS | High school MS |
|---|---|---|
| causal conjunctions (external) | 29.11 | 12.81 |

As Table 8.25 illustrates, causal conjunctions also decreased in the oral discourse data, falling by more than half. While this could once again be attributed to the task or topic, these findings line up to some extent with what Mohan et al. (2002) discovered. It may be the case that the older students have alternative ways to construct causality and therefore depend less on conjunctions. Certainly they are using more causal participants at the later ages. They are also using more causal processes, as Table 8.26 shows. Higher numbers of causal participants and processes suggest that the developmental path of cause is moving along the axis from conjunctions towards entities.

**Table 8.26: The path of causal processes**

| | Primary MS | High school MS |
|---|---|---|
| causal processes | 1.88 | 6.41 |

#### 8.2.2.5 External and internal conjunctions

Veel hypothesized that as students move through science they are greeted by a decrease of external conjunctions and an increase of internal conjunctions as the text becomes less a reflection of the here-and-now and the knowledge becomes more and more constructed through the language alone. The data from this study show that there was little use of internal conjunctions, as Table 8.27 shows, and what examples there were, were found only in the high school classes, supporting Veel's view that internal conjunctions increase. Yet processes of proof, a more grammatical way of constructing internal meaning than through conjunctions, showed a trend that was a reversal of what would be expected, with the younger students indicating a higher frequency of occurrences. It should be noted, however, that there was only one occurrence of one process in the primary mainstream corpus compared to five examples using two processes at the high school level. A larger corpus is needed before final conclusions are made on these processes of proof.

**Table 8.27: The path of proof**

| | Primary MS | High school MS |
|---|---|---|
| internal conjunctions | 0 | .28 |
| processes of proof | .94 | .56 |

### 8.2.2.6 Other features of causality

Veel's hypotheses have now been addressed, but the developmental path of cause as Mohan et al. perceive it leaves room for more comment. First, the data showed a decrease in the number of causal and means circumstances and an increase in the number of time and place circumstances, as Table 8.28 illustrates. Given that the predicted movement would be from time to cause, it seems odd that both conjunctions and circumstances in this research appear to be moving in an opposite direction.

Finally, the data show that there was a developmental shift from the non-use to the use of temporal processes, as Table 8.29 shows. Whereas the primary class used none, the high school class chose from three different processes. As with the causal processes, this trend suggests that there is a move towards more grammatically metaphoric constructions.

**Table 8.28: The path of circumstances**

| | Primary MS | High school MS |
|---|---|---|
| circumstances of cause | 1.88 | 0 |
| circumstances of means | 1.88 | 0.56 |
| circumstances of time | 0 | 1.67 |
| circumstances of place | 15.96 | 20.89 |

**Table 8.29: The path of temporal processes**

| | Primary MS | High school MS |
|---|---|---|
| temporal processes | 0 | 1.39 |

### 8.2.2.7 Mapping out the findings

Table 8.30 shows that with the exception of category of quality (no causal and temporal qualities were in the data), there was a visible shift in the direction of grammatically metaphoric constructions as well as a shift towards causal features as the constructions became more metaphorical. Causal and temporal processes were used more in the older grades, as were participants and metaphorical entities in general. The largest increase in the metaphorical entities occurred with processes and with qualities which have become nominalized, suggesting that the older students have a higher level of ability to manipulate the lexicogrammar. Halliday (1993) stated that this ability begins at about grade eight, and although this research cannot verify that claim, it does support the idea that this ability develops at some point between grade two and nine.

If the developmental path remains, as Veel (1997) suggested, framed around the two indicators—an increase in virtual entities (nominalizations and abstractions) and particular shifts in the use of conjunctions— it is not clear from this study's corpus analysis how development occurs from the more temporal/sequential language of the hands-on activity to decontextualized causal language. There is indeed an increase in nominalizations as the students age, supporting Mohan et al.'s recommendation to include the move towards grammatical metaphor, but as noted in Section 8.2.2.2, abstractions did not seem to follow this path. Whereas it was noted that this may have been a result of the particular topic, it may also have been a product of the oral interaction which allowed students to offer their ideas, whether they were right or wrong. Several students attempting different explanations for the same phenomenon has the potential to raise the number of entities, or the number of any other language features, in ways that a text written by an expert might not.

**Table 8.30: The developmental path of cause for the mainstream students**

figures are averaged per 1000 words

| | relator | circumstance | process | quality | entity (general metaphoric entities) |
|---|---|---|---|---|---|
| proof (internal) | Gr. 2 Gr. 9<br>0 .28<br>**YES** | | Gr. 2 Gr. 9<br>.94 .7<br>**NO** | | Gr. 2 Gr. 9<br>0 16.99<br>**YES** |
| causal (external) | Gr. 2 Gr. 9<br>29.11 12.81<br>**NO** | Gr. 2 Gr. 9<br>3.76 .56<br>**NO** | Gr. 2 Gr. 9<br>1.88 6.41<br>**YES** | | Gr. 2 Gr. 9<br>.94 4.46<br>**YES** |
| temporal (external) | Gr. 2 Gr. 9<br>25.35 51.11<br>**YES** | Gr. 2 Gr. 9<br>15.96 22.56<br>**YES** | Gr. 2 Gr. 9<br>0 1.39<br>**YES** | | Gr. 2 Gr. 9<br>0 2.51<br>**YES** |

This corpus analysis does not show how development occurs between temporal and causal conjunctions as Veel has suggested, although there is some evidence that there is a shift from external to internal conjunctions. Temporal conjunctions increased while causal ones decreased in frequency in this study, whereas Veel had predicted the opposite, and Mohan et al. had found that both temporal and causal conjunctions decreased. While these different findings could be attributed to corpus sizes, the discrepancy in the current research could also be attributable to differences in mode. The written text in Veel's examples and in the encyclopedias examined by Mohan et al., is construing knowledge in less context-dependent language for an audience which is not required to respond to questions. The content of these written texts is assumed to be factual, with less guesswork and speculation than what may be occurring in the oral interactions between the interviewers and the students. Looking back at the questions which guided the younger students' interviews, it is possible to find reasons for the higher frequency of causal conjunctions. For example, the interviewer asked the students *how do you know* (three times) and *why* (three times), frequently encouraging students to add to others' responses to these questions which they often did, using similar causal conjunctions. Because these types of questions elicit answers which contain causal conjunctions such as *because* and *if,* it could be said that the teacher's selection of questions and the interactional nature of the classroom may have affected the types and quantities of causal language features being produced.

Similar evidence for explaining the discrepancies in conjunction use is available for the high school students' high use of temporal conjunctions. As mentioned in Section 8.2.2.3, a large part of what the interviewer did with the high school students was elicit recounts of the experiments and demonstrations, with questions such as *why* and *how do you know* arising only within the context of the recounts and from the natural interactions. In fact, whereas the interviewer accounted for 52.56 percent of the total word count of the primary school interview (only the students' words were included in the corpus), her participation made up only 29.93 percent of the high school interviews, suggesting that there were fewer opportunities at the higher level to influence the linguistic choices of the students regarding time or cause conjunctions.

Despite the differences found among the various studies, it appears that the developmental path of cause must take into consideration the move from the more congruent forms to the more metaphorical constructions, as Mohan et al. suggested. Beyond noting that the explanations revolve around temporal and causal language features, this study is not conclusive regarding shifts between time and cause; more research would need to be done to explore the oral interaction factor as it relates to, for example, the numbers of temporal and causal conjunctions which appear.

### 8.2.3 The developmental path of cause: The ESL/mainstream speakers

If the high school ESL students were as adept at constructing causal explanations as their mainstream counterparts, it would be indicated by little development on the causal path with very similar numbers for the two groups. As Table 8.31 shows, this was not the case. Within conjunctions, the same pattern as the mainstream primary to high school students exhibited emerged with similar differences in numbers. As with the mainstream comparison, the discrepancy between this study's corpus results and those of Mohan et al. (2002) with regards to the temporal conjunctions may be due to corpus size or mode.

**Table 8.31: The developmental path of cause for high school ESL/mainstream**

figures are averaged per 1000 words

| | relator | | circumstance | | process | | quality | entity (general metaphoric entities) | |
|---|---|---|---|---|---|---|---|---|---|
| | ESL | MS | ESL | MS | ESL | MS | | ESL | MS |
| proof (internal) | 0 | .28 | | | 0 | .7 | | 11.37 | 16.99 |
| | **YES** | | | | **YES** | | | **YES** | |
| causal (external) | 30.53 | 12.81 | 1.47 | .56 | 4.21 | 6.41 | | 0 | 4.46 |
| | **NO** | | **NO** | | **YES** | | | **YES** | |
| temporal (external) | 29.68 | 51.11 | 30.31 | 22.56 | 0 | 1.39 | | 0 | 2.51 |
| | **YES** | | **NO** | | **YES** | | | **YES** | |

The ESL high school students used almost twice as many circumstances associated with time and sequence (e.g., circumstances of time and place) as the mainstream primary students, pushing them ahead of the mainstream high school students. The use of circumstances of time and place would seem to be easily influenced by the particular topics; the ESL students' numbers may have been inflated by, for example, their discussion of changes in the state of water throughout the four seasons, explanations which would have necessitated temporal circumstances such as in summer and in the fall. Circumstances of cause and means appear to be much less dependent on the topic and were used infrequently by all groups. Moreover, the one circumstance of cause that was used by the ESL students in this corpus was grammatically incomplete. In any case, no research to date has explored the developmental trends of circumstances to compare these findings to. Further research is needed before the developmental path can be established with regard to this type of language feature.

The ESL students at the high school level used no processes of proof, but as Section 8.2.2.5 suggested, a larger corpus is needed before any trustworthy conclusions can be made. With regards to the temporal and causal processes, the results are similar to the mainstream path, except that these ESL students were using causal processes more than twice the number of times as the primary mainstream students. This finding could be interpreted as indicating that the ESL high school students are farther along the developmental path than are the mainstream primary students, at least concerning causal processes, but they are still not performing at the level of the mainstream high school students. This is reinforced by examining the list of causal processes used by each group; the mainstream grade nine students revealed a much larger vocabulary of causal processes.

Causal and temporal participants were not used by the ESL students, which was similar to the mainstream primary students. The discourse of ESL students yielded a much higher number of metaphoric processual and quality entities, suggesting that they were perhaps farther along the developmental path towards the ability to use grammatical metaphor than the mainstream primary students had been. As Chapter 7 indicated, however, these ESL students had great difficulty shifting between more congruent forms such as *explode* or *react* to more metaphorical constructions such as *explosion* or *reaction*. In other words, although these students exhibited nominalizations in their corpus, there is evidence that these nominalizations may have been acquired as single lexical items, and that the students are not easily able to use them productively.

When the two primary school groups are compared (see Table 8.32), the results look very different. With regards to processes of proof, the mainstream students showed higher frequencies, as they did with temporal participants. Otherwise, it seems as though the path towards grammatical metaphor is too far ahead for these students, who appear to be constructing causal explanations primarily through conjunctions and circumstances. The fact that there is minimal grammatical metaphor apparent is not surprising given the students' young ages. What is interesting here is that Veel's hypotheses about the decrease in temporal conjunctions and the increase in causal ones is revealed only in the data of the younger speakers, who appear to have few other linguistic features available to rely on in their construction of causality. The results here should be read with caution, however, given the small corpora involved.

**Table 8.32: The developmental path of cause for primary school ESL/mainstream**

figures are averaged per 1000 words

| | relator | circumstance | process | quality | entity (general metaphoric entities) |
|---|---|---|---|---|---|
| proof (internal) | ESL 0<br>MS 0<br>**NO** | | ESL .51<br>MS .94<br>**YES** | | ESL 2.04<br>MS 0<br>**NO** |
| causal (external) | ESL 26.46<br>MS 31.92<br>**YES** | ESL .5<br>MS 3.76<br>**YES** | ESL 2.4<br>MS 1.88<br>**NO** | | ESL 0<br>MS 0<br>**NO** |
| temporal (external) | ESL 33.59<br>MS 25.35<br>**NO** | ESL 18.3<br>MS 15.96<br>**NO** | ESL 0<br>MS 0<br>**NO** | | ESL 0<br>MS .94<br>**YES** |

### 8.2.4 The developmental path of cause: The ESL speakers

As Table 8.33 shows, when the data from the ESL primary and high school students were compared, Veel's hypothesis regarding the number of temporal conjunctions decreasing while the number of causal ones increase was supported. The number of temporal and causal circumstances also increased, as did the number of causal processes and metaphoric entities of proof used internally. This suggests that generally speaking, the older students' explanations were more causal than temporal based on their use of conjunctions, but that their temporal relations contained more grammatically metaphoric constructions in the form of circumstances. In these results, the only counter-argument to the suggestion that the ability to use grammatical metaphor was greater at an older age was the reduction in the use of internal proof processes—the primary ESL students used more than the high school ESL students—but as previously mentioned, the number of these language features in the corpora was generally low. When looking at causal constructions overall, conjunction use increased but so did the use of grammatical metaphor around cause.

**Table 8.33: The developmental path of cause for the ESL students**

figures are averaged per 1000 words

| | relator | circumstance | process | quality | entity (general metaphoric entities) |
|---|---|---|---|---|---|
| proof (internal) | Gr. 2: 0; Gr. 9: 0 **NO** | | Gr. 2: .51; Gr. 9: 0 **NO** | | Gr. 2: 2.04; Gr. 9: 11.37 **YES** |
| causal (external) | Gr. 2: 26.46; Gr. 9: 30.53 **YES** | Gr. 2: .5; Gr. 9: 1.47 **YES** | Gr. 2: 2.4; Gr. 9: 4.21 **YES** | | Gr. 2: 0; Gr. 9: 0 **NO** |
| temporal (external) | Gr. 2: 33.59; Gr. 9: 29.68 **NO** | Gr. 2: 18.3; Gr. 9: 30.31 **YES** | Gr. 2: 0; Gr. 9: 0 **NO** | | Gr. 2: 0; Gr. 9: 0 **NO** |

Metaphoric entities of time and cause did not appear in the interview data of the ESL students at either age level, although examples of general nominalizations appeared more frequently in the speech of the older students. As noted earlier, however, the older ESL students frequently had a great deal of trouble manipulating the grammar involved in creating these nominalizations.

### 8.2.5 The use of the negative as a resource for meaning

As Section 8.2.1.6 described, the younger students used the negative to construct explanations during their interviews more than did the older students, and the ESL students used negation more often than the mainstream students. These findings suggest that the younger students and the ESL students were using negation as a strategy to double their meaning-making potential in that for every statement *X*, there can be a statement *not X*. But if Skyrms's (1986) notion of necessary and sufficient conditions, presented in Section 1.8.1, is considered, it can be argued that the use of the negative also has the potential to change the meaning relationship between causes and their effects.

Skyrms in fact argued that negation changes sufficient conditions to necessary ones and vice versa (Skyrms, 1986, p. 87):

5. If A is a sufficient condition for B, then ~A is a necessary condition for ~B.
6. If C is a necessary condition for D, then ~C is a sufficient condition for ~D.

Even though in broader cause and effect terms, the relationship appears to be much the same, different meanings have been constructed with regards to the conditions through which these causes might bring around effects because of the choice to use or not to use the negative.

Using Skyrms's examples, the relationship between these meanings described above can be seen more clearly. With regards to proposition five above, Skyrms stated that if being run over by a steam roller is a sufficient condition for death, not being run over is certainly a necessary condition for not dying. Proposition six shows that if the presence of oxygen is a necessary condition for combustion, its absence (non-presence) is a sufficient condition for not combusting. The relationship between what causes what remains much the same in each case, as mentioned above, but there is a finer distinction with regards to sufficient and necessary conditions for bringing the effects about. The use of the negative offers the speaker a choice of constructions for one or the other meaning, and the appropriate choice shows how the student understands the topic. In other words, combustion does not always occur when oxygen is present, and death can occur from incidents other than being run over; if students make incorrect assumptions, they might not be understanding the relationships being taught. The use of the negative, therefore, appears to offer a way to ensure that the appropriate condition is being constructed, even when perhaps the speaker lacks the resources to construct the condition using the positive.

Difficulty with the lexicogrammar as it concerned overt negatives was brought up in Section 7.4.2. There it was suggested that students may have been using negatives such as *no* or *not* because they were not able to construct more grammatically metaphorical clauses. The following two sentences were offered as a parallel:

- So in winter the heat in the air is not... enough so they can't keep the water in liquid state... so—
- Without enough heat in the winter, water changes from liquid to solid.

Both state sufficient conditions, but the first, spoken by ESL student Tony in Ms. Armstrong's class, used overt negatives in both clauses to construct his meaning. The second, posed as a more grammatically metaphoric construction, uses a hidden negative (Perera, 1984) in the first clause to construct a similar sufficient condition.

In sum, then, the younger students and the ESL students, who appear to be less adept at manipulating the lexicogrammar, tended to have higher frequencies of the negative in their explanations. Skyrms described the role that negatives play in changing necessary conditions to sufficient ones and vice versa, offering a potential explanation for why these higher frequencies may occur: The students want to construct a specific condition but do not have the resources available in the positive to do so. Of course, the corpora for this study was limited, and the research design did not set out to explore the types of meanings—sufficient or necessary conditions—that the students were attempting to construct, but it seems plausible that the younger students and the ESL students were employing the negative to construct the meaning they believed was appropriate for the relation. Future studies would be needed to explore this idea further.

### 8.2.6 Summary of research question two

Section 8.2.2 described in detail the developmental paths of cause which surfaced from the corpus numbers of the mainstream oral discourse. In general, the path moved along the temporal and causal line from the less to the more grammatically metaphorical language characteristic of adult-level scientific discourse, as Mohan et al. (2002) suggested. With regard to time and cause, however, the results of this study are inconclusive in that they did not line up with either Veel's (1997) or Mohan et al.'s predictions. As discussed in Section 8.2.2.7, this could have resulted from the low corpus numbers or the characteristics of the oral interactions.

From Section 8.2.3, the findings suggested that the idealized developmental path which Mohan et al. described when examining their encyclopedia data also resembles the path that the ESL students in this study are on to become more like their mainstream counterparts. The high school ESL students are on the developmental path of cause, trying to catch up with their mainstream speakers in all aspects of grammatical metaphor. The results of this study show this trend through the frequencies of causal language items examined, but similar findings have been noted before, even if they have not been stated in the same terms. Schleppegrell (2002), for example, observed that university-level ESL students have considerable difficulties with the lexicogrammar of scientific English when producing written science reports. The findings from the current study suggest strongly that it may be worthwhile to emphasize the more grammatically metaphorical forms when teaching science language at the higher grades, once the basic ability to construct causal meanings through conjunctions and circumstances has been established.

The primary students, on the other hand, did not exhibit many examples of grammatical metaphor, supporting Halliday (1993), who argued that this is because they have not yet reached an age where they begin to show signs of its regular use. This may be a factor in young ESL speakers' later success: When they are faced with the more difficult metaphorical discourse later, they may have already acquired a good, native-like grasp of congruent language, and together with their mainstream counterparts will learn the higher level science language at a later age.

## 8.3 The developmental paths of concepts and language

As indicated in the research by Mohan et al. (2002) and shown to some extent in this study, there appears to be a tendency towards a developmental path of causal language which moves semantically from time through cause to proof, and grammatically from conjunctions through processes towards nominalizations, or along what Halliday (1998) referred to as the general drift of grammatical metaphor. This developmental path is also visible when examining the knowledge constructed through the classroom discourse, as shown by the concept maps in each of the four data chapters.

Drawing concept maps from discourse and showing a path in conceptual development, as was done in this study, is not a novel approach, as discussed in Chapter 2. From the maps constructed in this study, it can be seen that the discourse interactions of the primary school grades contained fewer concepts and fewer relations amongst them than did the maps drawn from the high school discourse. Moreover, the section noted that as the grade level became higher, the discourse constructed maps with fewer everyday, observable concepts and larger numbers of technical and metaphorical terms. Although the two age levels in this study differ in a key way from Novak's Paul, whose interview discourse constructed maps about the same topic at two different maturity levels, the maps in this study show similar patterns regarding the numbers and types of terms which appear at each level. The growth in the number of concepts and their relations does not reveal much beyond the size and depth of the units at each level. It cannot indicate growth in this study because the topics taught at each level are different; the nature of the topics themselves may determine the number of concepts involved.

When the relations in the current study's concepts maps were examined, a similar pattern emerged. Whereas the connections at the primary level involved primarily relational processes with some material processes, the causal process *make,* and in the case of Mrs. Montgomery's class, one relation signifying evidence (although a term of evidence was not used), the connections at the higher level included many more propositions which involve cause, evidence, and grouping. Both concept maps at the higher level used similar propositions between concepts. This suggests that both the ESL and mainstream students needed to be able to construct the same types of propositions amongst the concepts, but as Chapter 7 described, the ESL students had few resources with which to do this.

In sum, the current study shows a similar pattern of development between the primary grades and the high school grades with regards to the types of concepts which are included in the maps constructed at each grade level. What is also evident is that the relations amongst concepts further show a developmental pattern from a high use of the more descriptive/ classifying relations such as *is* and *has* to ones which involve more cause and evidence. What is further revealed from the findings in this study, however, is that there may be a developmental path occurring between the ESL and non-ESL students at the high-school level with regards to the types of concepts involved. The pattern which emerges when the focus is put on the number of everyday terms versus the number of metaphorical terms is similar to those of Paul (Novak, 1998) and Cary (Jones, et al. 2000). The concept map constructed through the discourse of Ms. Armstrong's class contains more everyday concepts and fewer metaphorical concepts than the one constructed from Mr. Peterson's interactions. Although the differences in numbers is not striking, given that the topic being taught in both contexts is supposed to prepare the students for the next grade of chemistry, and given that many of the concepts in the map involve more than a simple one-to-one representation, these findings raise questions as to whether these students were conceptually farther behind than their mainstream counterparts in the same grade level.

## 8.4 Implications

This broad study, with both its qualitative, social practice aspect and its quantitative, corpus linguistics approach, has several implications for researchers and educators, including those in curriculum design. In the following pages, these implications will be presented and discussed.

### 8.4.1 Implications for researchers

Rupp (1992) stressed the importance of dialogue between students and teachers during hands-on science as an essential part of learning both science and science language. Martin, Sexton, and Gerbovich (2001) stated that teachers need to question students "so that students use the experiences of their explorations to construct scientific meaning" (p. 228). Henderson and Wellington (1998) commented that "the quality of classroom language is bound up with the quality of learning" (p. 36). Causal explanations—concept development, the building of taxonomies, and the relations among the concepts in the taxonomies—are being constructed regularly through classroom interactions while teaching and learning are taking place. The study described in this thesis has shown how the social practice of teaching and learning science can be examined from a linguistic perspective using systemic functional grammar and social practice theory. It also shows how concept development (or lack of) can be traced through the discourse of the teachers and students as they talk about what they are doing in science.

Whereas science education has put an emphasis on connecting new science knowledge with students' existing or background knowledge (see Howe, 1996), the social practice analysis used in this study has suggested that something more is happening than a straightforward connection between existing and new knowledge. Mr. Peterson, for example, constructed the students' background knowledge discursively using specific reflection and then brought it forward as general reflection related to the new science knowledge or theory he was attempting to construct. This could be seen through the lexicogrammatical choices he made—the use of, for example, exophoric terms and human participants in the specific reflection compared to the use of the timeless present and more grammatically metaphorical or technical terms in the general reflection. The type of analysis presented in this study can be used by researchers to highlight what is happening during science teaching and learning at the discourse level.

The social practice analysis was also able to show how Mrs. Montgomery was not using the students' background information in her teaching, but was using the students' experiences with the magnets to build new knowledge. In fact, the use of practical work in science is said to result in a development of knowledge which is needed to understand the natural world (Erickson et al., 1992). Hands-on, minds-on teaching and learning is not a new concept in science; practical exploration and discovery are said to be essential to meaning-making in science. But as Martin et al. (2001) asserted, experience alone is not sufficient for teaching and learning. Communication is also needed, but the idea of hands-on, minds-on science has not been mapped from a linguistic perspective. To do this, the social practice analysis presented in this study offers a useful way to examine the connections between the experience of hands-on work and the new knowledge being constructed during the minds-on part of the activity. In fact, Mrs. Sinclair's context offered a view on the type of language and knowledge that is constructed when the focus is on hands-on with little emphasis on minds-on. This study also showed how a focus on the text—Ms. Armstrong's context—plays out in teaching and learning in a different way than a focus on hands-on, practical work.

In sum, this study has implications for researchers in that they can use social practice theory to analyze the discourse of teaching and learning to see how science knowledge is being constructed through the language of classroom interactions. The analysis used here can reveal the similarities that exist at the discourse level, similarities which may not be apparent when looking at the connections between background and new knowledge or practical work and its relationship to theoretical understanding. Looking at the construction of meaning in this way can reveal the complexities of the interactions and help uncover areas where teaching and learning might be improved.

This study has also shown how Novak's concept mapping can be used to illustrate the causal explanations which are being constructed through the science discourse, thereby capturing the knowledge in a graphic which can be compared across various contexts. Novak's ideas have been used previously to show concept development in individuals, but the findings of this study show that concept mapping can be used to show how teachers' language choices might impact on the type of knowledge which students take away from the unit. Mrs. Sinclair and Mrs. Montgomery used basically the same experiments in the same magnet unit, but the knowledge which the discourse constructed in each context appeared to be noticeably different. Concept maps captured these differences as a static image, and the social practice analysis helped to show what was happening through the discourse. The dual perspective helped to reveal some of the complexities of science teaching and learning.

This study also highlighted the usefulness of using corpus analysis and concordancing techniques to explore the developmental path of causal language features, but it has also raised concerns about the use of small corpus sizes in making generalizations about this development. Larger corpora are recommended. Moreover, although this study has offered a selection of measures which can be used to examine causal discourse (a list compiled from the literature and used in the Mohan et al., 2002 study), examples of causal qualities were not addressed, and metaphorical terms were general rather than specific to cause or time, as noted in Chapter 8. This study has therefore shown that future research needs to continue to expand the list of discourse features which can be used by computers to measure the development of causal explanations in oral and written science.

Along this line, the study has also attempted to reveal the problems that arise when trying to perform a lexical density analysis on a corpus of oral interactions and interviews. As Section 8.2.2.1 discussed, there were frequent examples of responses to interview questions which contained lists of lexical units, thus offering the potential for artificially increasing the lexical density results and the types and numbers of causal features used. Moreover, there were frequent examples of grammatically incomplete clauses by the ESL students which could again affect the findings. How computer concordancing can handle these issues in interactive discourse proves to be an issue which needs to be addressed if further work is done on large quantities of oral discourse, particularly when that discourse is from ESL students who are struggling to construct grammatically metaphorical explanations. Should the data be idealized to resemble written monologue in order to determine the lexical density, or should it be left as "messy" real discourse? If it is cleaned, how much cleaning should be done with regards to grammatical completeness and repetition by various participants in the interactions? If it is left in its original state, how can the computer handle repetitions and false starts? Should the repetitions be counted as non-lexical items such as speech hesitations? If so, how can this be done using concordancing software on large corpora? These questions highlight the issues which arise when causal discourse development is examined from an oral, rather than written, perspective.

Finally, this study has offered researchers a starting point for examining—from a quantitative, systemic functional linguistic corpus-based approach—the developmental path of cause in oral causal explanations in general and in causal explanations by ESL speakers specifically. An examination of oral discourse development is important because it is typically through oral interactions in the classroom that the ability to talk about cause and effect in science is developed. This study has presented findings around the grade two level and the grade nine level for mainstream and ESL speakers and held these findings up to previous studies which concerned the developmental path of cause in the writing of experts. The implications from this are that there is a path through time and cause from the less to the more grammatically metaphoric, and the challenge to future researchers is to build upon these general patterns so that educators can be better informed about the development of cause-and-effect language.

### 8.4.2 Implications for educators

The language of school, or academic discourse, differs from the language of everyday in the types of taxonomies it builds and in its use of context-reduced language, technical terms, and abstract concepts. In schools, children are introduced to new experiences for which they need new language. Painter (1996) stated that the relationship between "learning through language and developing language itself" (p. 79) is a dynamic one, and that causal discourse is a key ideational resource for construing field and explaining ideas logically. This study has shown that it is important for teachers to develop the language of science by introducing the proper labels for the concepts. A comparison of the concept maps from Mrs. Sinclair's and Mrs. Montgomery's class suggests that the knowledge which is constructed by using appropriate labels looks remarkably different from the knowledge which children might use if such language is not reinforced. Similar findings appear in the two maps of the high school contexts.

This study has also suggested that the interactions between the teachers and the students play a key role in connecting experience (both past and current) to the knowledge or theory that is being taught. By moving systematically between specific and general reflection, teachers can build theory from experience and connect the new, target knowledge to the students' existing understandings. Although the skillful use of questioning to help students learn is not a new topic in science education—Martin et al. (2001) asserted that "questions can make the difference between learning from *meaningful* manipulation of materials and *meaningless* messing around" (p. 269, italics in original)—this study has illustrated the type of knowledge which can be constructed when questioning is not employed on a regular basis, and has provided empirical support for emphasizing the use of careful questioning to move between specific and general reflection, particularly when such questioning involves reinforcing the appropriate labels for concepts and asking students to consider the relationships among these concepts. It should be cautioned, however, that the experiences of the students need to be considered when using these to build knowledge. Duff (2001) observed that ESL students are often at a disadvantage in mainstream classes when the talk revolves around popular culture and other topics which may not be familiar to them.

The findings of this study also highlight the need for teachers to consider the order in which the concepts are presented so as to successfully build meaning with the students. In Mrs. Montgomery's class, for example, the teacher ordered the experiments in such as way that she could use the experiences which the students were building through their hands-on tasks as well as interlocking terms based on their earlier acquired conceptual understanding of *attract* and then used it to help the students understand *repel.* Mrs. Sinclair, on the other hand, did not, and many of her students offered observational language when they saw the magnets repel, and did not appear to understand why this was happening. Mr. Peterson exhibited a similar strategy as Mrs. Montgomery by building students' understanding of physical properties, and then using this knowledge to help solidly construct the concept of mixtures. Ms. Armstrong, on the other hand, did not construct an adequate knowledge base of properties, and her students struggled with the mixtures task because they were unable to associate the parts of the mixtures with the physical properties which would help identify them. Moreover, the definitions offered for both mixtures and compounds referred to properties, leaving these concepts somewhat fuzzy if understood at all.

Martin et al. (2001) recommended that concept maps be used by teachers as unit organizers so that the concepts and their relationships could be kept in mind as the lessons progressed. These authors commented that without concept maps, teachers' lessons may become disconnected enough that the learners may fail to make the targeted connections. Teachers might also teach only what they choose to teach or what they can remember about the topic. In the current study, it was pointed out that Ms. Armstrong had students do a problem-solving task without having given them the appropriate background knowledge needed to complete it, and had chosen an experiment which may not have been ideal for teaching the concept she was attempting (see the examples of mixture separation discussed in Section 7.3.3). Had Ms. Armstrong had a clear concept map, she may have better seen the connections she needed to make. Similarly, if Mrs. Sinclair had been given a target concept map for her unit, she may have focused more on making sure the students learned and understood the concepts on the map and the relationships among them. This is, of course, not a guarantee, and future research would need to be carried out to see what impact the availability of concept maps for units would have on teachers' practices.

As the concept maps for the primary grades suggested in this study, the number of concepts the students needed to handle was quite low, as is the number of relations amongst the concepts in the teaching unit. In the high school grades, even as early as grade nine, the number of concepts presented in one teaching unit was noticeably larger, as was the number of connections to be made. The lower number of concepts contained in the units of the earlier grades—and in particular, the lower frequency of abstract and metaphorical concepts—may make it easier for non-science specialists to keep track of how the concepts fit together and therefore make it easier to teach the subject successfully. Yet at the high school level, a deeper knowledge of how the concepts fit together may be necessary as there are many more to build with the students. In other words, as the maps become more complex, the task of the teacher becomes more difficult, and the understanding of the science by the teacher needs to be deeper. Furthermore, as the maps showed, in the higher grades, the language becomes more metaphorical, farther away from the congruent actions and experiences. Therefore, the deeper complexity of the concept maps in the high school units suggests that teachers at this level should have a greater amount of training in the sciences so that they have a solid understanding of what the target concepts are, how the concepts relate to each other, and how they are constructed through language. ESL teachers without a science background, while sincere in their attempts to help the students construct science knowledge, may not have this depth of understanding and may be therefore constructing very different knowledge bases for their students who, when they move into non-ESL science classes, may find themselves lacking the conceptual knowledge that their mainstream peers possess.

At the primary grade level, on the other hand, science specialists may not be as necessary. The number of abstract concepts on the map is lower, as is the overall number of concepts to keep track of. In other words, the topic is not probed as deeply or as broadly as it is in high school. Yet as this study has suggested, it is important for primary teachers to understand the smaller number of concepts and how they fit together with other concepts so that they can provide their students not only with the experiences of the experiments but also with an adequate conceptual framework on which future experimentation can build and which can be constructed linguistically.

The findings from the quantitative part of this study reinforce Veel (1997) and Mohan et al. (2002) in suggesting that there is a developmental path of cause, particularly with regards to the development of grammatical metaphor. The younger students did not exhibit any facility with the metaphorical language, but the high school mainstream students were quite proficient in its use. The ESL students at the high school age appeared to be farther behind on this path than the mainstream students, and the discourse examples showed that they struggled to find the right words and grammar to construct their explanations while relying on a fairly small set of causal relations. Given that the high school ESL students appeared to have such trouble with the more grammatically metaphorical constructions, the implications from this study suggest that content-based ESL instructors in these contexts should consider explicitly teaching students how to manipulate the lexicogrammar rather than simplifying the textbook language for them or having them work on technical vocabulary and sentence-level connectors. Recommendations for working with students to understand how to construct and deconstruct grammatically metaphorical language do not stem from this study alone (see, for example, Derewianka, 1990; O'Toole, 1996; Schleppegrell, 2001; Unsworth, 2001a), but this study reinforces those recommendations by highlighting the problems the ESL students were having with this type of language and quantifying the resources that they were using.

Finally, the finding that there is more happening with causal language than simple sentence-level transitions and processes argues in favor of more collaboration between science educators, who know how to "talk the talk," and language educators, who are trying to teach their ESL students to understand and use this talk. Shifting register from everyday, non-science language to the language of the specialist—or even the language of the high school science class—involves more than just vocabulary, yet technical terms have long been the primary focus of teachers teaching science language. If ESL teachers are not science specialists, as discussed above, collaboration between science and language teachers with regards to the concepts being taught and the relationships among these concepts can help language specialists who are not trained in science, such as Ms. Armstrong, teach their ESL students the language of science while simultaneously constructing the same knowledge as do specialist teachers, such as Mr. Peterson, with their mainstream students.

## 8.5 Future directions

This study has traced the development of causal discourse from two perspectives, both a qualitative examination of how the participants in four different contexts construct explanations through their interactions in the classroom, and a quantitative look at the numbers and types of causal features being used by the students in these four contexts. The study is the first systemic functional comparison of the oral discourse of primary and secondary learners as well as the first to compare ESL and non-ESL speakers in this way. As such, it helps map the general area of causal discourse development and provides a springboard for future research in the area.

From the qualitative perspective, this study has traced the teaching and learning practices in four contexts. As with all case studies, however, investigating a wide number and variety of cases can inform the field more than individual cases can, and so future case studies done similarly but at different grade levels and in different contexts (e.g., physical sciences versus biological sciences) would be useful in examining the various approaches teachers have. Furthermore, given that the social practice approach was not able to show which practice from these four contexts was more effective for promoting student learning, future studies could explore this by combining a social practice discourse analysis and an experimental design to show both *how* teachers are working with their students to construct causal explanations through the discourse and *which* practices lead to optimum learning situations. In other words, future studies might investigate from a linguistic perspective what the measures of a "good teacher" might be. Findings from studies such as those could also reveal how teacher intervention can be used positively to improve the performance of ESL students in high school science.

Future studies might also make use of social practice theory to examine in more detail from a linguistic perspective what is happening during hands-on, minds-on teaching and learning, where the activities are occurring within the same lesson, and compare this to teaching and learning from lecture-based courses, where the labs are done in separate time slots. Research in this area may help shed light on some of the difficulties which some students may have moving from a high school context, which has both lecture and lab in the same school "period" to the university context, which typically separates labs from lectures in the same course. Analyses done from a social practice perspective may also be interesting when examining computer-based science teaching. Given the importance of interaction between teachers and students which this study has highlighted, it would be interesting to investigate the use of computers in teaching science, as the interactions between computers and their operators—and even those between two students working at one computer—appear to differ from those between traditional teachers and students.

This study has also suggested that the knowledge built by the interactions of the classroom, as shown by concept maps drawn from this discourse, reflects the inclusion or exclusion of appropriate concept labels and the teaching of the relationships among these concepts. In other words, when a topic is taught using everyday labels for concepts which may therefore not be fully developed with regards to their scientific meanings, the knowledge which is constructed through the discourse is different from that which is constructed with careful consideration of the concepts, their labels, and the relationships they have with other concepts. Future research could look at this in more detail, with studies designed to examine from a linguistic perspective the usefulness of having teachers who are not science specialists use concept maps to help them teach topics which they may not have a great depth of knowledge in. Although concept maps have been advocated as organizers for teachers, research from a social practice perspective can provide linguistic evidence for whether concept maps can help different teachers with differing levels of background knowledge in the sciences construct similar knowledge with and for their students.

From a quantitative perspective, this is the first time a study has looked at the developmental path with ESL students and with oral discourse. As such, it has identified broad patterns and therefore provided a foundation for further work, but more research is needed to clarify and add to these findings. The corpus of oral causal explanations needs to be expanded and made public, and the best ways to examine this using computers need to be identified, particularly with regards to issues of lexical density in oral interview discourse. Future studies are also needed to investigate further the semantic progression in the oral explanations of students, as this study used interviews to elicit explanations and the interviewer's questions may have influenced the types of meanings which the students constructed.

From the general notion of causal discourse development, future studies are needed to identify measures which can be used to evaluate stages of development, particularly in written discourse. This is critical for the purpose of valid and reliable assessment of causal explanations. This study has used linguistic features which have been identified in previous research and by using them has shown a broad developmental pattern over about a seven-year period, but further research needs to examine more subtle differences if it is to inform the field of assessment, particularly computer-based assessment. This may be a worthwhile pursuit given that contemporary tests of written English appear to avoid this type of writing passage (see Mohan & Slater, 2004), and yet many international—and therefore ESL—students are tested for their writing ability prior to being accepted (or rejected) for graduate science programs at universities where English is the language of instruction and evaluation.

Finally, future research should also examine the construction of causal discourse across languages, not only to inform translators and teachers of English for Specific Purposes, but to help students who arrive in the English-speaking academic world at the high school age. If the development of grammatical metaphor occurs at around the early high school age in other languages, as Halliday (1993) claims it does in English, what happens to students who have not learned to handle this type of academic discourse in their first language and then come to a country where English is the dominant language to find they are farther behind the path in their second language? Is the ability to handle grammatical metaphor a potential marker in establishing a useful definition of the notion of double semilingualism (see Skutnabb-Kangas, 1981)? Understanding more about the development of causal explanations in English and across languages will help both researchers and educators understand and assist in the construction of this type of academic discourse.

## 8.6 Reflections on the study

I had two purposes in mind when I designed this study, as reflected in the two research questions which guided my inquiry: to explore how teachers and students develop causal explanations, and to examine the linguistic resources, including grammatical metaphor, which the students used to explain their understandings of the topics under investigation. I believe the findings from this study have helped to identify patterns in teaching as well as general patterns of development of causal language features. I also hope that they have helped to highlight the connections between language development and the development of science concepts.

This study provided a broad look at the development of causal explanations from a systemic functional perspective, and in doing so, has offered opportunities for me to learn about and practice different approaches to examining the data. The personal voyage through the data was long and diverse, compounded by the sheer quantity made available by including multiple groups within each context when available, a choice I consciously made to reduce the possibility that one group of students might be remarkably different from another in the way they constructed explanations, or that the teacher worked with one group differently than he or she did with another studying the same topic. Yet with regards to the quantity of data and the variety of lenses on them, I would not have opted for any other approach, as I believe that the design of this study permitted the broad examination that I set out to do.

If I were to have changed anything about the way I carried out this study, I would have attempted to control the types of questions I asked the students so that the findings might be more informative with regards to the semantics of the explanations offered in the interviews. In the current study, the focus was on eliciting explanations from the students in a way that created a natural conversation about what the students were learning; in other words, guiding questions were drafted, but follow-up questions were based on the students' initial responses. I did not control whether these were related to time and cause, and so the developmental path through semantics remains something to investigate in future studies.

The process of doing this study has highlighted for me the connections between language and content in developing knowledge in science. Given that I am a language educator and not a science teacher, however, it is perhaps more relevant to me that the study has reinforced the importance of looking at causal discourse when considering how we can improve the academic literacy levels of both ESL and non-ESL students, and the critical role grammatical metaphor appears to play in this type of discourse. I have suggested that the general pattern of the developmental path of cause in oral discourse resembles the path which was discovered in larger samples of writing, notably in Mohan et al. (2002). As I indicated in Section 8.5, however, the search for the path of development should not end with this study. More questions need to be asked and answered. This study represents four cases only, and despite the interesting differences and similarities which I have identified in these cases, further work needs to be done before the path which I have begun to forge here can be considered stable and broad enough to provide a solid basis for assessment and curriculum. The path lies open for exploration.

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# APPENDIX 1: THE STATION INSTRUCTIONS FOR MRS. SINCLAIR'S EXPERIMENTS

## STATION ONE

Which things will a magnet pick up?

1. **Prediction:** Sort the objects into two groups. In one group, put the things you think the magnet will attract. In the other group, put the things you think the magnet will not attract.
2. **Test:** Test each object using the magnet. Write the results in your booklet. Put a star in front of the objects you predicted correctly.
3. **Conclusion:** What did you notice about the objects that the magnet attracted?
4. Put all the objects away.

**Spelling help:**

| | | | | | |
|---|---|---|---|---|---|
| paper clip | eraser | penny | cardboard | nickel | dime |
| quarter | plastic | bottle cap | key | felt | wood |
| pencil | crayon | button | straw | rock | safety pin |

## STATION TWO

How can we show that the invisible force of magnets is real?

1. Place the pencil in the pencil holder.
2. Drop one ring magnet, white side down, over the pencil.
3. Drop the second ring magnet, white side up, over the pencil.
4. Observe what happens.

**Questions:** Why don't the two rings touch each other? What is keeping them apart?

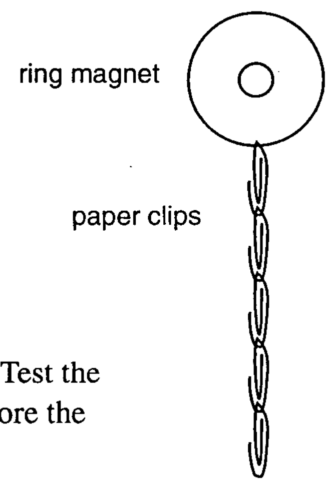
5. Push on the top magnet to make it go down on the bottom magnet.

**Questions:** What do you feel? Do the two magnets stay together when you stop pushing?

6. **Conclusion:** How can you show that an invisible force is real?
7. Make a diagram of this experiment in your magnet booklet.
8. Put all the objects away.

## STATION THREE

Which of these magnets will pick up the most paper clips?




1. **Prediction:** Predict which magnet will be
   the strongest
   the next strongest
   the weakest.

Number them in your booklet.
   the strongest = 1
   the next strongest = 2
   the weakest = 3

2. **Test:** Look at the diagram. Put some paper clips on the table. Test the ring magnet first. See how many paper clips it will pick up before the clips start to fall off. Write the results in your magnet booklet.

3. Test the bar magnet and the horseshoe magnet, too. Remember to write the number in your booklet.
4. **Conclusion:** Which magnet picked up the most paper clips? The strongest magnet picked up the most. Which magnet was the strongest? Were your predictions correct?
5. Put all the objects away.

**STATION FOUR**

Which of these magnets will pull a paper clip from the greatest distance?

1. **Prediction:** Predict which magnet will be
   the strongest
   the next strongest
   the weakest.

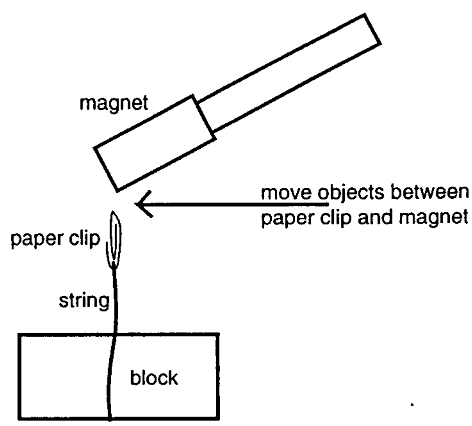
Number them in your booklet.
   the strongest = 1
   the next strongest = 2
   the weakest = 3

2. **Test:** Place the ring magnet at the bottom of the lined paper. Place a paper clip at the top of the paper.
3. Slowly slide the ring magnet towards the paper clip until the clip begins to move towards the magnet. How far was the magnet from the paper clip when the paper clip started to move? Write your results in your magnet booklet.
4. Do the same test with the bar magnet and the horseshoe magnet. Remember to write your results in your magnet booklet.
5. Which magnet is the strongest? The strongest magnet is the one that moved the paper clip from the farthest away.
6. Were your predictions correct?
7. Put all the objects away.

**STATION FIVE**

Which things will the force of magnetism pass through?

1. **Prediction:** Look for station #5 in your booklet. Write yes if you think magnetism will pass through the object. Write no if you think magnetism will not pass through it.
2. **Test:** Look at the diagram below. Use the magnet so that the paper clip and the string stay up in the air, like the ones in the diagram.
3. Test the different objects by passing them between the magnet and the paper clip. If the paper clip falls, the magnetism does not pass through the object. If the paper clip does not fall, the force of magnetism is passing through the object.



4. Write your results in your magnet booklet.
5. **Conclusion:** What objects does magnetism pass through?
6. Put all the objects away.

**STATION SIX**

How can you use a magnet to make a magnet?

1. Touch the paper clip with the nail. What happened? Is the nail a magnet?
2. Rub the nail across the magnet about 200 times. Rub the nail in one direction only.
3. Hold the nail near the paper clip. What happened? Is the nail a magnet? If the nail is not a magnet, rub it across the magnet again.
4. How many paper clips can the nail hold in a chain?
5. Draw a diagram of the nail holding the paper clips.
6. Put all the objects away.

**STATION SEVEN**

How can you make a compass by magnetizing a needle?

1. The earth is like a big magnet. It has a north pole and a south pole like other magnets.
2. Float the cork in the middle of the bowl of water.
3. Magnetize the needle by rubbing it 200 times across the magnet. Carefully lay the needle across the cork.
4. What happened? Did the needle turn so that it's pointing north and south?
5. Draw a diagram of the compass you made.
6. Tap the needle four times on the edge of the table. Put the needle, the cork, and the magnet away.

**STATION EIGHT**

How can you make the invisible force of magnetism visible?

1. Look for the plastic sheet that has iron filings inside it. Put the ring magnet under the plastic sheet.
2. Carefully tap the plastic sheet. Can you see patterns in the iron filings? These patterns show the lines of force of the magnets.
3. Draw a diagram to show the pattern of the ring magnet.
4. Do the same thing with the bar magnet and the horseshoe magnet. Draw the patterns for those magnets in your magnet booklet, too.
5. Put all the objects away.

**STATION NINE**

What are the strongest parts on a bar magnet?

1. **Prediction:** Predict where you think the strongest parts of a bar magnet are. Write your predictions in your magnet booklet.
2. **Test:** Put some pins on the table. Pass the bar magnet over the pins. Observe what happens.

3. **Conclusion:** Which parts of the magnet are the strongest parts? The strongest part of the magnet is the part that held the most pins.
4. Draw a diagram of your magnet, showing the pins it held.
5. Put all the objects away.

**STATION TEN**

What happens when you cut a magnet in half?

1. **Prediction:** First test the magnet. Does it pick up a paper clip? Predict what you think will happen when you cut the magnet in half. Write your prediction in your magnet booklet.
2. **Test:** Use the scissors to cut the magnet in half. Test each half of the magnet to see if it's a magnet. Does each half of the magnet pick up a paper clip? Write down your observations.
3. **Conclusion:** What happens when you cut a magnet in half? Write your conclusion in your magnet booklet.
4. Put all the objects away.

**STATION ELEVEN**

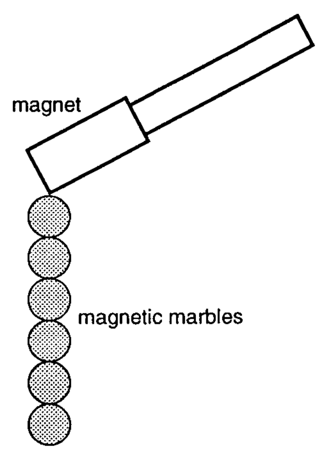
What can you find out about the poles of a magnet?

1. Put the south poles of two magnets together. What happens? Did the magnets pull together (attract) or push apart (repel)? Write your results in your magnet booklet.
2. Put the north poles of two magnets together. What happens? Did the magnets pull together (attract) or push apart (repel)? Write your results in your magnet booklet.
3. Put the south pole of one magnet near the north pole of another magnet. What happens? Did the magnets pull together (attract) or push apart (repel)? Write your results in your magnet booklet.
4. Conclusion: What kinds of poles attract? What kinds of poles repel? Write the rule in your magnet booklet.
5. Put all the objects away.

**STATION TWELVE**

How many magnetic marbles can you suspend in a chain?

1. **Prediction:** Predict how many magnetic marbles you can suspend in a chain. Write your prediction in your magnet booklet.
2. **Test:** Look at the diagram. Put the magnetic marbles on the table. Pick up one. Make your chain by suspending a second marble from the first one, like in the diagram.
3. **Conclusion:** How many marbles can the magnet hold in a chain before it breaks? You can try two times.
4. Write your answer in your magnet booklet. Draw a diagram of your longest chain.
5. Put all the objects away.



## APPENDIX 2:
## MRS. SINCLAIR'S MAGNET BOOKLETS

______________________'s

# Magnet Book

**Station #1**

**Attracted to the magnet**

______________________

______________________

______________________

______________________

______________________

______________________

**Not attracted to the magnet**

______________________

______________________

______________________

______________________

______________________

______________________

**Conclusion:** Magnets attract things made of ______________________.

**Station #2**

Draw a diagram of the experiment you did that shows magnetism is real.

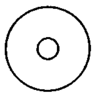
**Diagram:**

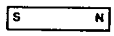
**Conclusion:** You can show that an invisible force is real by showing ______________________.

## Station #3

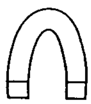
Which magnet will pick up the most paper clips?

**Prediction** **Test**

______  ______

______  ______



______  ______

**Conclusion:** The ______________

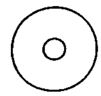
magnet is strongest because _______

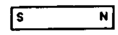
___________________________ .

## Station #4

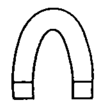
Which magnet will pull a paper clip from the greatest distance?

**Prediction** **Test**

______  ______ cm.

______  ______ cm.



______  ______ cm.

**Conclusion:** The ______________

magnet is strongest because _______

___________________________ .

## Station #5

Which objects will magnetism pass through?

| **Prediction** | | **Test** |
|---|---|---|
| ______ | paper | ______ |
| ______ | cardboard | ______ |
| ______ | glass | ______ |
| ______ | wood | ______ |
| ______ | plastic | ______ |

**Conclusion:** Magnetism passes

through ______________________

things.

## Station #6

**Diagram:**

**Conclusion:** To make a magnet from a nail, you must __________ the nail across the magnet in the __________ direction for about ______________ times.

## Station #7

**Diagram:**

**Conclusion:** I can make a compass by magnetizing a needle and then floating the needle on a __________ in a dish of __________________ .

## Station #8

**Diagram 1:**

**Diagram 2:**

**Diagram 3:**

**Conclusion:** I used ____________ __________________ to make the invisible forces of magnetism visible.

## Station #9

**Prediction:** I think the strongest parts of the magnet are ______________ __________________________ .

**Diagram:**

**Conclusion:** The strongest parts of the magnet were ______________ __________________________ .

## Station #10

**Prediction:** I think that if you cut a magnet in half, ____________________

______________________________

**Observations:**
1st half: ____________________

______________________________

2nd half: ____________________

______________________________

**Conclusion:** When you cut a magnet in half, ____________________

______________________________.

## Station #11

**Observations:**

- South poles together:

______________________________

- North poles together:

______________________________

- One north pole and one south pole:

______________________________

**Rule:**

____________________ poles attract.

____________________ poles repel.

## Station #12

How many magnetic marbles can you suspend in a chain?

**Prediction:** ____________________

**Test:** 1st try: ____________________

2nd try: ____________________

**Diagram:**

## Extra activity

- Make a stage for a play. Use a cardboard box for the sides and back. Use a cookie sheet for the bottom.
- Make the characters for your play out of cardboard. Put a paper clip on the bottom of each character.
- Use magnets to make your characters move on the stage.
- Write the play and practise it. When you are ready, perform your play for the class.
- Ideas: a favourite story
  a favourite fairy tale

# APPENDIX 3:
# MRS. MONTGOMERY'S EXPERIMENTS

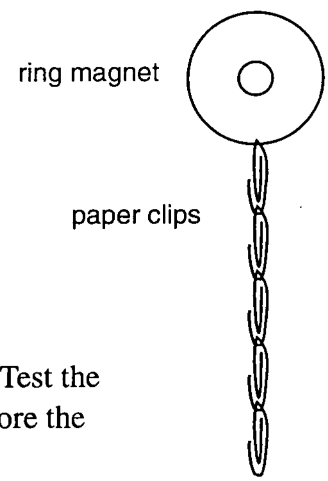
**EXPERIMENT ONE: What does a magnet attract?**

1. **Prediction:** Sort the objects into two groups. In one group, put the things you think the magnet will attract. In the other group, put the things you think the magnet will not attract.
2. **Test:** Test each object using the magnet. Write the results in your booklet. Put a star in front of the objects you predicted correctly.
3. **Conclusion:** What did you notice about the objects that the magnet attracted?

**EXPERIMENT TWO: The strongest parts**

1. **Prediction:** Predict where you think the strongest parts of a bar magnet are. Write your predictions in your magnet booklet.
2. **Test:** Put some pins on the table. Pass the bar magnet over the pins. Observe what happens.
3. **Conclusion:** Which parts of the magnet are the strongest parts? The strongest part of the magnet is the part that held the most pins.
4. Draw a diagram of your magnet, showing the pins it held.

**EXPERIMENT THREE: The strongest magnet**



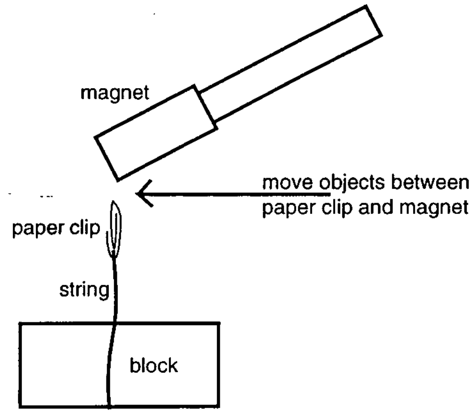

1. **Prediction:** Predict which magnet will be
   the strongest
   the next strongest
   the weakest.

   Number them in your booklet.
   the strongest = 1
   the next strongest = 2
   the weakest = 3
2. **Test:** Look at the diagram. Put some paper clips on the table. Test the ring magnet first. See how many paper clips it will pick up before the clips start to fall off. Write the results in your magnet booklet.
3. Test the bar magnet and the horseshoe magnet, too. Remember to write the number in your booklet.
4. **Conclusion:** Which magnet picked up the most paper clips? The strongest magnet picked up the most. Which magnet was the strongest? Were your predictions correct?

**EXPERIMENT FOUR: The power of magnetism**

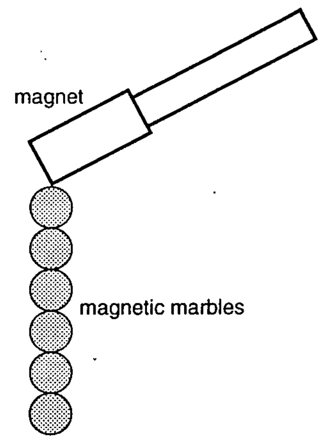
1. **Prediction:** Write yes if you think magnetism will pass through the object. Write no if you think magnetism will not pass through it.
2. **Test:** Look at the diagram. Use the magnet so that the paper clip and the string stay up in the air, like the ones in the diagram.
3. Test the different objects by passing them between the magnet and the paper clip. If the

paper clip falls, the magnetism does not pass through the object. If the paper clip does not fall, the force of magnetism is passing through the object.
4. Write your results in your magnet booklet.
5. **Conclusion:** What objects does magnetism pass through?




**EXPERIMENT FIVE: Magnetism in a chain**

1. **Prediction:** Predict how many magnetic marbles you can suspend in a chain. Write your prediction in your magnet booklet.
2. **Test:** Look at the diagram. Put the magnetic marbles on the table. Pick up one. Make your chain by suspending a second marble from the first one, like in the diagram.
3. **Conclusion:** How many marbles can the magnet hold in a chain before it breaks? You can try two times.
4. Write your answer in your magnet booklet. Draw a diagram of your longest chain.




**EXPERIMENT SIX: Making a magnet**

1. Touch the paper clip with the nail. What happened? Is the nail a magnet?
2. Rub the nail across the magnet about 200 times. Rub the nail in one direction only.
3. Hold the nail near the paper clip. What happened? Is the nail a magnet? If the nail is not a magnet, rub it across the magnet again.
4. How many paper clips can the nail hold in a chain?
5. Draw a diagram of the nail holding the paper clips.

**EXPERIMENT SEVEN: Making a compass**

1. The earth is like a big magnet. It has a north pole and a south pole like other magnets.
2. Float the cork in the middle of the bowl of water.
3. Magnetize the needle by rubbing it 200 times across the magnet. Carefully lay the needle across the cork.
4. What happened? Did the needle turn so that it's pointing north and south?
5. Draw a diagram of the compass you made.

**EXPERIMENT EIGHT: Showing the force**

1. Look for the plastic sheet that has iron filings inside it. Put the ring magnet under the plastic sheet.

2. Carefully tap the plastic sheet. Can you see patterns in the iron filings? These patterns show the lines of force of the magnets.
3. Draw a diagram to show the pattern of the ring magnet.
4. Do the same thing with the bar magnet and the horseshoe magnet. Draw the patterns for those magnets in your magnet booklet, too.

**EXPERIMENT NINE: Attracting and repelling**

1. Put the south poles of two magnets together. What happens? Did the magnets pull together (attract) or push apart (repel)? Write your results in your magnet booklet.
2. Put the north poles of two magnets together. What happens? Did the magnets pull together (attract) or push apart (repel)? Write your results in your magnet booklet.
3. Put the south pole of one magnet near the north pole of another magnet. What happens? Did the magnets pull together (attract) or push apart (repel)? Write your results in your magnet booklet.
4. Conclusion: What kinds of poles attract? What kinds of poles repel? Write the rule in your magnet booklet.

**EXPERIMENT TEN: An invisible force**

1. Place the pencil in the pencil holder.
2. Drop one ring magnet, white side down, over the pencil.
3. Drop the second ring magnet, white side up, over the pencil.
4. Observe what happens.

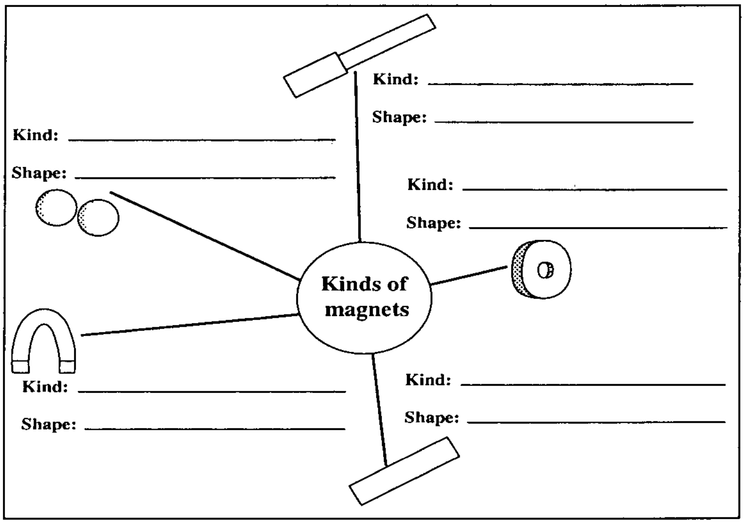
**Questions:** Why don't the two rings touch each other? What is keeping them apart?

5. Push on the top magnet to make it go down on the bottom magnet.

**Questions:** What do you feel? Do the two magnets stay together when you stop pushing?

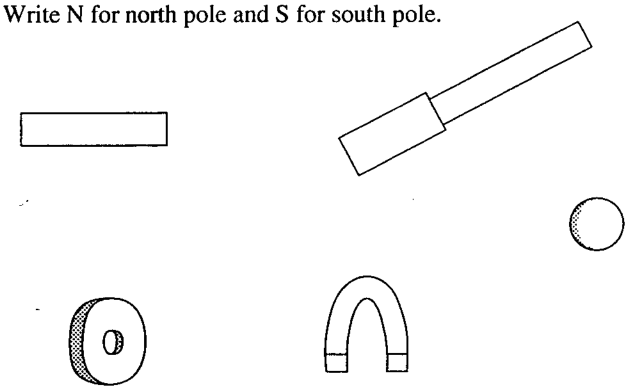
6. **Conclusion:** How can you show that an invisible force is real?
7. Make a diagram of this experiment in your magnet booklet.

# APPENDIX 4: KEY VISUALS IN THE WRITING TASKS




There are many kinds of magnets.

Where are the poles on these magnets?
Write N for north pole and S for south pole.



Each magnet has a north pole and a south pole.

# Magnets

| attract | do not attract |
|---|---|
| | |
| | |
| | |
| | |
| | |
| | |

Magnets attract some things but not others.

# Magnetism

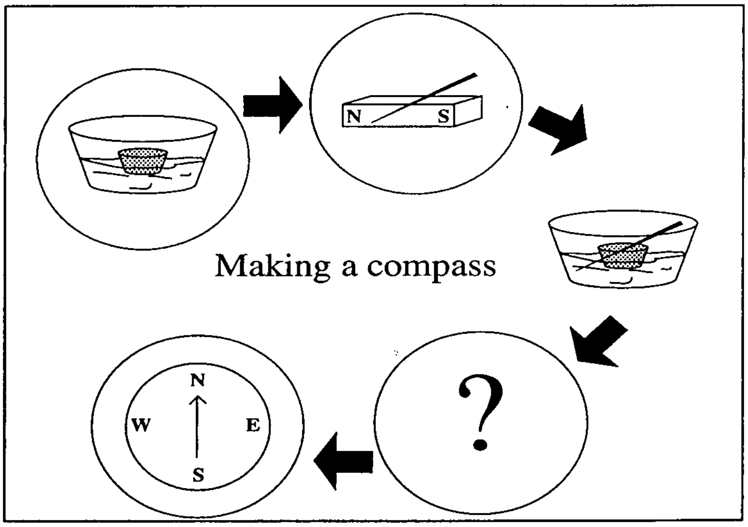
| passes through | passes along |
|---|---|
| | |
| | |
| | |
| | |
| | |
| | |

The force of magnetism can pass through objects.

## The Rule of Magnetism

| if | | | then |
|---|---|---|---|
| north | + | north | |
| north | + | south | |
| south | + | south | |
| south | + | north | |

The force of magnetism always works the same way.




How to make a compass

# APPENDIX 5: MR. PETERSON'S STUDENTS' ENTITIES

**(89 types for 497 tokens)**

| | |
|---|---|
| conclusion | 1 |
| discussion | 1 |
| expansion | 1 |
| conservation | 8 |
| demonstration | 2 |
| calculation | 11 |
| condensation | 3 |
| observation | 1 |
| reaction | 10 |
| chemical reaction | 5 |
| endothermic reaction | 2 |
| exothermic reaction | 2 |
| gas-producing reaction | 1 |
| precipitation reaction | 1 |
| temperature change | 4 |
| changes in matter | 1 |
| change | 3 |
| chemical change | 7 |
| mass change | 1 |
| difference | 3 |
| the fizzing | 1 |
| pressure | 1 |
| reactants | 7 |
| suspended substance | 2 |
| product | 7 |
| **25 METAPHORIC PROCESSUAL** | **86** |

| | |
|---|---|
| whiteness | 3 |
| weight | 9 |
| mass | 28 |
| heat | 22 |
| cold | 2 |
| **5 METAPHORIC QUALITY** | **64** |

| | |
|---|---|
| solution | 11 |
| suspension | 2 |
| temperature | 8 |
| cold temperature | 1 |
| low temperature | 1 |
| math | 1 |
| heat energy | 3 |
| kinetic energy | 1 |
| energy | 12 |
| properties | 2 |
| active metal | 1 |
| active liquid | 1 |
| molecules | 1 |
| atmosphere | 1 |
| joules | 1 |
| kilojoules | 2 |
| calories | 1 |
| chemical | 10 |
| atoms | 3 |
| **19 ABSTRACT TECHNICAL** | **63** |

| | |
|---|---|
| sodium carbonate | 17 |
| calcium chloride | 13 |
| copper sulfate | 9 |
| bunsen burner | 15 |
| test tubes | 23 |
| lead two nitrate | 14 |
| potassium iodide | 14 |
| carbon dioxide | 6 |
| florence flask | 2 |
| erlenmeyer flask | 1 |
| sodium hydrogen carbonate | 21 |
| test tube holder | 1 |
| calcium carbonate | 1 |
| sodium | 2 |
| the plastic tubing | 1 |
| the starting temperature | 1 |
| original state | 1 |
| thermometer | 1 |
| substance | 8 |
| frostbite | 4 |
| mixture | 2 |
| metallic objects | 1 |
| equipment | 4 |
| dilute acid | 2 |
| (flint) striker | 9 |
| liquid crystals | 1 |
| ingredient | 1 |
| stopper | 1 |
| a sealed container | 1 |
| computers | 1 |
| petri dish | 1 |
| the cone of the fire | 2 |
| beaker | 11 |
| hydrogen (gas) | 7 |
| calcium | 11 |
| magnesium (ribbon) | 12 |
| hydrochloric acid | 36 |
| copper | 4 |
| copper wire | 13 |
| **39 CONCRETE SPECIALIZED** | **275** |

| | |
|---|---|
| law of conservation of mass | 9 |
| **1 ABSTRACT SEMIOTIC** | **9** |

# APPENDIX 6: MS. ARMSTRONG'S STUDENTS' ENTITIES

**(95 types for 617 tokens)**

| | |
|---|---|
| information | 3 |
| definition | 1 |
| reaction | 5 |
| evaporation | 3 |
| attraction | 2 |
| repulsion | 1 |
| oxidation | 3 |
| operation | 2 |
| covalent bonding | 4 |
| change | 4 |
| physical change | 2 |
| chemical change | 3 |
| chemical reaction | 1 |
| chemistry change | 10 |
| **14 METAPHORIC PROCESSUAL** | **44** |
| liquid | 4 |
| solid | 4 |
| heat | 9 |
| cold | 1 |
| **4 METAPHORIC QUALITY** | **18** |
| chemical | 4 |
| matter | 1 |
| compound | 5 |
| electricity | 2 |
| equipment | 1 |
| neutron | 17 |
| particle | 3 |
| charge | 2 |
| electron | 61 |
| proton | 19 |
| negatively side | 1 |
| positive charge | 1 |
| negative side | 1 |
| positive side | 1 |
| no charge | 5 |
| plus charge | 2 |
| minus charge | 2 |
| noble gas | 1 |
| outermost shell | 7 |
| formula | 2 |
| energy | 2 |
| molecule | 4 |
| the liquid state | 1 |
| state | 2 |
| electric shell | 2 |
| electrical charge | 1 |
| electron shell | 8 |
| atomic level | 1 |
| electron charge | 1 |
| shell | 10 |
| temperature | 8 |
| element | 72 |
| atom | 5 |

| | |
|---|---|
| outer shell | 12 |
| **34 ABSTRACT TECHNICAL** | **267** |
| base | 2 |
| hydrogen | 44 |
| sodium | 5 |
| acid | 2 |
| iron | 6 |
| nitro | 2 |
| aluminum | 3 |
| rust | 1 |
| ammonia | 1 |
| optical nerve | 4 |
| optic nerve | 4 |
| cornea | 8 |
| lens | 5 |
| muscle | 6 |
| sclera | 11 |
| nucleus | 2 |
| brain | 8 |
| iris | 2 |
| choroid coat | 2 |
| retina | 12 |
| pupil | 2 |
| periodic table | 6 |
| family | 8 |
| mixture | 12 |
| simple sugar | 11 |
| nitrogen | 1 |
| water vapor | 1 |
| steel wool | 9 |
| test tube | 3 |
| atomic model | 1 |
| H2O | 1 |
| H | 3 |
| chlorine | 3 |
| CL | 2 |
| NaCl | 2 |
| potassium | 9 |
| oxygen | 62 |
| carbon | 8 |
| carbon dioxide | 9 |
| magnesium | 2 |
| **40 CONCRETE SPECIALIZED** | **285** |
| diagram | 1 |
| **1 ABSTRACT SEMIOTIC** | **1** |
| experiment | 1 |
| **1 ABSTRACT INSTITUTIONAL** | **1** |
| ruler | 1 |
| **1 CONCRETE EVERYDAY** | **1** |