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Chapter 7

A SEMIOTICS DISCOURSE ANALYSIS FRAMEWORK: UNDERSTANDING MEANING MAKING IN SCIENCE EDUCATION CONTEXTS

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ABSTRACT

A Four–Level Semiotics Discourse Analysis framework is proposed to understand meaning making when scientific theories are used as explanatory models in Science Education contexts such as classrooms. This Discourse Analysis framework is derived from a semiotics perspective of scientific knowledge being interpreted as signed information and from functional linguistics approaches as articulated by M.A. K. Halliday and J. Lemke. Halliday's and Lemke's approaches to Discourse analysis are organized around three generalized semiotic meanings that relate to social action, roles of people, and organization of the text or sign. However, to understand how different signs (referred to as semiotic modalities) are used to construe meanings in Science Discourse, I argue that in addition to Halliday's and Lemke's three-level typology, a fourth aspect of meaning, the epistemological, is necessary. The epistemological aspect of meaning will refer to the nature of science, including the values involved in constructing scientific theories/knowledge. A historical analysis of the creation of scientific knowledge shows that shared values shape the nature of scientific knowledge. Hence, the epistemological aspect is integral to meaning making in Science Discourse. The application of this Four-Level Semiotics Discourse Analysis framework is illustrated within two physics teachers' teaching practices. Analysis of the way these physics teachers signify and communicate scientific knowledge and the nature of science through multiple modalities such as verbal language and visual diagrams is presented. The proposed analytical framework has the potential to guide semiotics research in the Science Education field[1] and illuminate meaning making in Science Discourse. It furthers the field of semiotics by considering how signs communicate epistemological aspects of meaning.

[1] I wish to thank Douglas Karrow for his thoughtful review and insightful suggestions.

INTRODUCTION

A current research trend in Science Education focuses on the role of multimodal representations in constructing meanings in science (Airey and Linder, 2009; Jewitt and Kress, 2003; Kozma, Chin, Russel, Marx, 2000; Kress, Jewitt, Ogborn, and Tsatsarelis, 2001; Lemke, 2002; Prain and Waldrip, 2006; Roth and Lawless, 2002). Multimodal representations/signs are also referred to as multiple semiotic modalities. Research based on multimodal representations is premised upon communication characterized by multiple modes of representation such as oral and written language, images, and actions in contrast to oral and written language (linguistic mode) being the forms of representation. This begs the question: How do multimodal signs or multiple semiotic modalities signify meanings in Science Discourse and how can these signs be interpreted in Science Education contexts?

Before answering these questions, I will clarify how I use the term Science d/Discourse. I use Gee's (2005) notion of discourse (lower-case d) and Discourse (upper-case D) to distinguish between two different d/Discourse modes occurring in Science Education contexts. Gee uses the term discourse (lower-case d) to refer to communicative events where the focus is on a linguistic mode, e.g., written language and the term Discourse (upper-case D) to describe social events that involve a coordinated pattern of words, actions and interactions, values, beliefs, symbols, tools, objects, times, and places. The term Science Discourse (upper-case D) as used in this chapter will include the linguistic mode (discourse), gestures, values, tools, and actions associated with the discipline of science.

The application of a semiotics approach to Science Education contexts illuminates the meaning potential of semiotic signs used in Science Discourse. An understanding of the multiple ways signs can be interpreted in Science Discourse may enhance the process of teaching and research in Science Education. In this chapter, I propose a Four-Level Semiotics Discourse Analysis framework to interpret how multimodal signs or multiple semiotic modalities such as verbal and written language, visual diagrams, gestures, and objects signify meanings in Science Discourse (upper-case D). Thereafter, the proposed Four-Level Semiotics framework will be used to interpret how two science educators use multimodal representations/signs to communicate scientific knowledge.

The chapter is organized in relation to the following semiotic-related questions:

1. How are signs used to signify meaning? This involves looking at the uses and functions of signs from semiotic perspectives.
2. What common signs are used to signify scientific knowledge? This involves a historical inquiry as to how these signs came into existence and how scientific knowledge encodes their meaning(s). The historical analysis supports the development of the proposed Semiotics Discourse Analysis framework.
3. Why do the signs used in Science Discourse mean what they mean? This involves describing the structural features of multimodal signs and analyzing the signs using the proposed analytical framework.

In the sections that follow, I begin by drawing on the works of semioticians such as Pierce and Eco to provide a brief overview of how signs signify meanings. I then discuss scientific knowledge as a system of signed information and illustrate how meanings may be signified and interpreted in Science Discourse. Thereafter, I propose a Four-Level Semiotics Discourse Analysis framework for interpreting Science Discourse and illustrate its use in the analysis of two physics teachers' teaching of the concept 'inertia'.

INTERPRETING SIGNS

How are signs used to signify meanings? Semiotics is the study of meaning making through signs and is premised on the notion that signs have a triadic quality (Danesi and Santeramo, 1999). There is the physical sign itself (e.g., word, gesture); the entity being referred to (e.g., object, idea), and the sign's meaning or signification. Various philosophers and semioticians (Saussure, 1999; Pierce, 1999; Eco, 1976) refer to the sign, its signified, and its signification/meaning by different terms and have represented this relationship as a triad (Figure 1). In figure 1, the signifier/physical sign/representaman can be words, gestures, physical objects and pictures that call attention to or signify an object, event, idea/concept or being (Pierce, 1999; Saussure, 1999). The signified is also referred to as the referent or object. The process by which the object, event, idea/concept is captured and organized in some way by the sign is a form of representation. Although, not historically accepted as a common view, signs or signifiers are, "seen as suggesting meanings rather than encoding them" (Danesi, 2007, p.73). According to Pierce (1999) a sign's meaning arises in its interpretation. Pierce (1999) explains that a sign "addresses somebody, that is, creates in the mind of that person an equivalent sign, or perhaps a more developed sign" (p. 72). Furthermore, this mental interpretation includes the emotions, ideas and feelings that the sign evokes for a person at that time. Pierce refers to the sign's meaning as the interpretant.

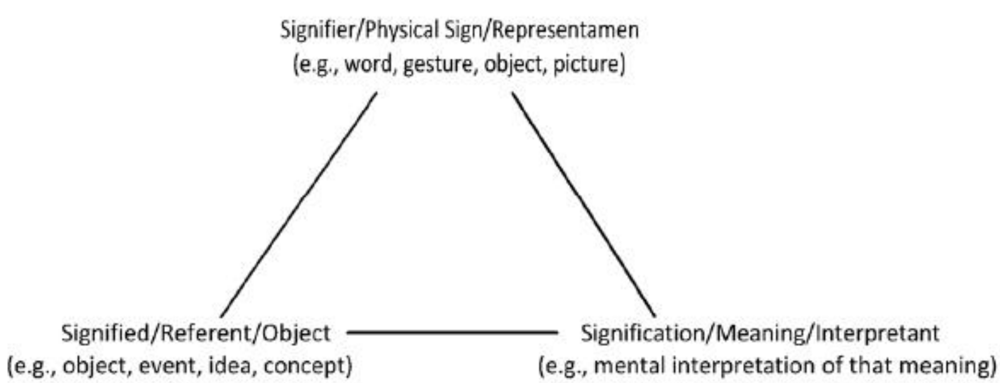


Figure 1. The triadic relationship of sign, referent, and meaning.

Pierce (1999) also describes three ways that signs are created – resemblance, relation, and convention – in turn represented through: icons, indexes, and symbols. Icons are signs resulting from resemblance, constructed to resemble their referents in some way (e.g., photographs, diagrams, models). Indexes are signs that show relations of some kind to something else in time, space, location (e.g., pointing finger, arrow, timeline graph, adverb – here, there, I, you, they). Symbols stand for some conventional practice (e.g., the V sign for peace, words, sentences, Greek letters representing constants in math) and in science, a knowledge system of society, examples of symbols include: terms, equations, and formulae.

Eco (1979) expands Pierce's (1999) notion of sign and describes a sign as "*everything* that, on the grounds of a previously established social convention, can be taken as *something standing for something else*" (p. 16). Eco illustrates this with the term "dog" – the term "dog" does not refer to a specific, real dog in the room; it refers to all dogs in the world which is a class or set that cannot be perceived as a real object by the senses. Hence, Eco (1979) states, "*Every attempt to establish what the referent of a sign is forces us to define the referent in terms of an abstract entity which moreover is only a cultural convention" (p. 66).* Eco sees the semiotic object as the content – a cultural unit conventionally assigned by society based on a system of rules or codes. The perspective of the referent as content fits well with scientific knowledge where referents are often abstract concepts such as 'force' and 'energy'.

Eco (1979) goes on to suggest that the interpretant can also take on many forms. For example, the word 'property' (sign/signifier) is used to signify a characteristic quality when used in relation to a physical object or it could signify an object such as owned land or real estate. Signs therefore do not represent or communicate one single meaning or interpretation. Additionally, Eco asserts that the meaning or interpretant of a sign can be another sign in another semiotic system (e.g., a drawing corresponding to a word), a definition in terms of the same semiotic system (e.g., 'salt' signifies 'sodium chloride'), an emotive association (e.g., 'dog' signifies 'love'), or a translation into another language. According to Danesi (2007, p.16), "all *signification* (be it denotative or connotative) is a relational and associative process – that is, signs acquire meanings not in isolation, but in relation to other signs and to the contexts in which they occur". Furthermore, he asserts that denotative meaning points out or identifies something (e.g., object, content) whereas connotative meaning includes all other senses including emotional ones that something elicits (Danesi, 2007). For example, the word 'dog' refers to a four-legged animal kept as a pet (denotative meaning) and also conjures the emotion of miserable when used as 'a life like a dog' (connotative meaning).

How is the sign interpreted? For Eco (1984) sign interpretation mostly occurs through abduction or hypothesis. To interpret a sign, a person requires a previously established frame of reference or rule. These rules may be already established or can be hypothesized or created. Codes "provide the rules which *generate* signs as concrete occurrences in communicative intercourse" (Eco, 1979, p.49). "Codes are systems of signs that people can select and combine in specific ways (according to the nature of the code) to construct messages, carry out actions, enact rituals, and so on, in meaningful ways" (Danesi, 2007, p. 75). Danesi distinguishes between social, mythic, knowledge, and narrative codes. Social codes are those that can be used to interpret social communication and interactions (e.g., the zone/distance a person keeps in different social situations indicates the degree of intimacy present); mythic codes (e.g., action heroes representing ideal personality traits); knowledge codes are those sign systems that enable knowledge such as mathematics, science, and philosophy to be represented and communicated (e.g., trigonometry), and narrative code is a story that portrays or represents human events as perceived in a particular timeframe (e.g., novel, newspaper article). Hence, a sign can be interpreted in many ways depending on the codes used. In relation to scientific knowledge, it is the knowledge code that primarily acts as a frame of reference for interpretation of signs.

SCIENCE AS A SEMIOTIC KNOWLEDGE SYSTEM

Science is a knowledge system of signed information (Danesi, 2007). Scientific knowledge encompasses theories, symbolic generalizations/ laws (e.g., f=ma), tools (e.g., constant proportion), models (e.g., force fields), methods (e.g., careful observations), processes (e.g., deductive experiments), and shared norms and values (Kuhn, 1962, McComas, 2008). From a historical point of view, scientific language evolved to classify, decompose, and explain the scientists' world view and became documented in the following major scientific genres – report, explanation, and experiment (Martin, 1993). As well, during this knowledge creation process, many technical terms such as 'motion' were derived from the nominalization (converting to a noun) of everyday words such as 'moved'. Communication of scientific knowledge in journal articles suggests that science is more than a knowledge system instantiated in written text; the way we represent and express scientific meanings is through a variety of signs or semiotic modalities including gestures and images (Jewitt and Kress, 2003; Roth and Lawless, 2002). Analyses of science journal articles (Lemke, 1998; Roth, Bowen, and McGinn, 1999) indicate that it is normal and essential to interpret the verbal text in relation to other semiotic systems. For example, Lemke found that many journal articles displayed results in a set of graphs and a table and referred to the graph and table in the written text. Roth et al. reported that scientific articles with graphical modes provided contextual information and instructions on how to interpret graphs in lengthy captions. Understanding scientific meanings thus depended on the reader being able to interpret the different semiotic modalities by looking at how multiple signs interact with each other and how multiple signs together communicate the meaning of the content. Further, Lemke showed that meaning-making in science also involved the constant translation of information from one modality to another as well as the integration of information from multiple modalities to re-interpret and re-contextualize information in one modality in relation to the other. The most common signs that are used by cultural convention to represent the content of western scientific knowledge are written definitions, mathematical equations, images, and graphs (Lemke, 1998) and in most cases the complete meaning or interpretation requires the use of two or more semiotic modalities, or even all semiotic modalities in relation to each other (Lemke, 2002; Roth and Bowen, 2000). Lemke (2002) also points out that while each semiotic modality expresses a slightly different meaning, all meanings add to the overall meaning of the concept; hence it is necessary to use multiple semiotic modalities simultaneously to represent, communicate, and interpret the meanings of science concepts.

Science as a semiotic system constitutes a body of knowledge generated by a community of scientists using sets of codes. Besides knowledge codes (e.g., symbolic generalizations and models) that guide how scientific knowledge is represented, communicated, and interpreted, value codes play a significant role in constructing and interpreting scientific knowledge. In response to shared values, Kuhn (1996) posits that probably the most deeply held values of the scientific community "concern predictions: they should be accurate; quantitative predictions are preferable to qualitative ones; whatever the margin of permissible error, it should be consistently satisfied in a given field"(p. 185). Another set of value codes held by scientists are those used to judge theories. Kuhn explains that these values "must, first and foremost, permit puzzle-formulation and solution; where possible they should be simple, self-consistent, and plausible, compatible, that is, with other theories currently deployed" (p. 185).

The notion that science is not primarily facts, laws, symbols, theories, and tools, but constitutes a code of values that guides how the scientific community constructs and validates scientific knowledge, suggests that any analysis of meaning making of Science Discourse should include how signs represent and communicate these shared values (epistemological aspect).

The shared values involved in constructing scientific knowledge also shape views about the nature of science. The nature of science includes perceptions about how science works, how scientists interact as a social group, and how society influences scientific knowledge (McComas, Clough, & Almazroa, 1998). How science has been perceived has evolved historically over time. For example, traditional beliefs of science communicated the notion of science as a static body of knowledge derived from facts based on neutral observation; these facts were objective and could be discovered by anyone with the right set of instruments (Kuhn, 2000). It was interpretation of the facts that gave rise to scientific laws and theories, the latter in turn being used to explain natural phenomena. The scientific method (experimentation) was the process used by scientists to discover true generalizations and secondary criteria such as accuracy, consistency with accepted beliefs, and breadth of applicability were also used to evaluate the correspondence of the belief "to the real, the mind-independent external world" (Kuhn, 2000, p. 114). Current portrayals of the nature of science are less objective and more interpersonal. Kuhn (1996, 2000) illustrates how science is a dynamic practice characterized by changes in belief over time. As such, he contends that observations are not independent of all prior beliefs and theories and it is through a process of negotiation involving the factual and the interpretative that scientists reach consensus about laws and theories. Kuhn (2000) states:

> These two aspects of the negotiation – factual and the interpretative – are carried on concurrently, the conclusions shaping the description of facts just as the facts shape the conclusions drawn from them. (p. 109)

Current views about the nature of science emphasize the creative, subjective, theory-laden, tentative, and durable nature of scientific knowledge, the historical, cultural, social, political, and economical influences on the creation of scientific knowledge, the importance of empirical evidence, and the use of inductive reasoning and hypothetico-deductive testing (McComas, 2008). Since learning science is characterized by the learning of a view of science (Roberts and Ostman, 1998), any consideration of meaning-making in Science Discourse should also incorporate an interpretation of what multiple modalities communicate about the nature of science (epistemological aspect).

The previous historical overview of science as a knowledge system provides a foundation for what follows. In figure 2, I illustrate the triadic semiotic relationship of sign, signified/referent, and its meaning/interpretation in relation to more contemporary and fluid interpretations of what constitutes scientific knowledge.

As discussed above, the content of science is constituted by concepts, laws, theories, and tools, scientific processes such as predicting and measuring, and values such as judging the validity of theories. Hence, in figure 2, I use the term content or scientific knowledge to indicate the signified/referent. The content, in this case scientific knowledge consists mainly of culturally assigned abstract entities such as concepts, theories and laws, processes, tools, and values.

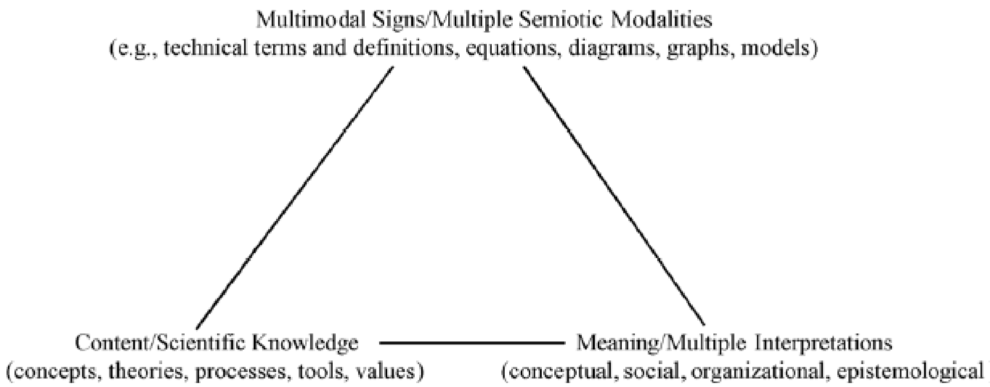


Figure 2. A semiotic relationship of sign, referent, and meaning for Science Discourse.

It should be noted that from a semiotics perspective, when a sign is used to signify the content, the sign first evokes an “image” or a mental picture of the content (Danesi, 2007). It is “the culture-specific interpretation that is assigned to that picture” that is called a concept (p. 17). Two types of concepts have been distinguished: a concrete concept is where the content can be observed in a direct way – be seen, heard, smelled, touched, or tasted; an abstract concept is where the content cannot be perceived in a direct sensory way. Concepts in science are mainly abstract ideas such as ‘gravitation’ or ‘symbiotic’ designating phenomena or categories of entities, events, or relations.

In Figure 1, a single sign is used to signify the content. However, in Science Discourse, a combination of signs signifies meanings (Lemke, 2002). Hence, in Figure 2, the physical sign signifying meaning is multimodal signs or multiple semiotic modalities. These multimodal signs in Science Discourse can be a combination of modalities such as technical terms and definitions, equations, diagrams, graphs, and models.

With regard to the third component of the triad, the meaning/interpretation, Halliday (1994) maintains that all meaning making in communicative events (Discourse) involve three aspects of meaning related to the social action, the roles of people and the organizations of the sign or text respectively. Drawing on the work of Halliday, Lemke (1998) proposed the following three aspects of meanings constructed during Discourse: presentational, orientational, and organizational. These three aspects of meaning and their application to Science Education Discourse will be explained in the succeeding section. Of significance to the interpretation component in Figure 2, is the idea (as shown by the brief historical analysis above) that scientific knowledge is construed by theories and symbolic generalizations (conceptual aspects) and shared values and the nature of science (epistemological aspects). Since Lemke argues that the different aspects of meaning are constructed simultaneously during interpretation, I extend Lemke's typology by considering an additional "epistemological" aspect of meaning. I propose that the interpretation of signs in Science Discourse (illustrated in Figure 2) involves multiple interpretations related to four aspects of meaning. All told, these four aspects of meaning – conceptual (presentational), social (orientational), organizational, and epistemological – comprise the Four-Level Semiotics Discourse Analysis framework useful in interpreting how multimodal signs represent and communicate meanings in Scientific Discourse.

A FOUR-LEVEL SEMIOTICS DISCOURSE ANALYSIS FRAMEWORK

Halliday's (1994) and Lemke's (1998) three-level typologies to explain how meaning making occurs in Discourse are grounded in Systemic-Functional theory that has its origins in the intellectual tradition of European linguistics that developed following the work of Saussure (1999). Lemke's framework will be elaborated as it extends the use of Halliday's typology for linguistic texts to include the visual-graphical mode, a mode that is commonly used to express scientific meanings.

Lemke (1998) outlines three aspects of meaning that are constructed during Discourse:

- a presentation of events, actions, relations, processes;
- an orientational stance towards and for the presentational content and participants; and,
- the organized and meaningful relations between elements of the discourse.

The presentational meaning in linguistics mode, according to Lemke (1998), reflects the way we use grammar to construct a theme or topic, or make predictions and arguments. The presentational function of meaning therefore describes participants, processes, relationships, and circumstances. It constructs what is actually taking place or what is actually happening in relation to associated participants (agents, instruments) and circumstances (where, why, under what conditions). For visual-graphical semiotic resources such as diagrams and graphs, presentational aspects manifest in elements (e.g., arrows) that are arranged to illustrate meaningful relations between elements about a concept or topic (Lemke). The orientational meaning involves an orientational stance (attitude and viewpoint) towards the presentational content and participants. Orientational aspects of meaning in linguistic mode refer to the statuses and roles of participants in the communicative event (e.g. friendly, hostile, formal) and social relationships between producer of text and reader/listener (e.g. pleased, displeased) (Lemke). Orientation also indicates the stance indicated by the text (e.g. an evaluation of the text as good or bad) and how the text positions the reader and the producer in relation to other viewpoints (Lemke). For visual graphics, typographical tools such as italics and boldface emphasize importance and act as orientational tools. The organizational aspect of meaning refers to the organizational relations between the parts of speech (Lemke, 1998). For example, in oral or written speech, clauses are combined in certain ways to produce meaningful sentences and paragraphs illustrating relationships such as cause-effect or whole-part relations. As well, the organizational aspects of visual diagrams such as typographical tools (e.g. geometric figures, arrows) and compositional tools (e.g. texture, colors) also indicate which elements are to be read in relation to each other (Lemke, 1998).

Drawing on these three aspects of meanings described by Lemke (1998) and the semiotic relationship of sign, referent, and meaning for scientific knowledge proposed within Figure 2, I describe the Four-Level Discourse Analysis framework for Science Discourse in relation to the following four aspects of meaning: conceptual, social, organizational/pedagogical, and epistemological.

Conceptual Aspect of Meaning

This aspect of meaning mainly indicates the denotative meanings (in this case the intended scientific meanings) expressed by multimodal signs during Science Discourse. The interpretation of signs is in response to the question: How do the multimodal signs represent and communicate the conventionally assigned meanings of scientific knowledge? The conceptual meaning is similar to Lemke's (1998) presentational meaning. In relation to Science Education Discourse, the conceptual aspect of meaning is mainly reflected by conceptual aspects such as scientific theories and laws, predictions and arguments, and scientific applications in a variety of contexts.

Social Aspect of Meaning

The social aspect of meaning focuses on the interpretation of signs in response to the question: How do multimodal signs position the participants in relation to each other and scientific knowledge? This meaning aspect is similar to Lemke's (1998) orientational meaning. In Science Education Discourse, the social aspect of meaning will refer specifically to how multimodal signs position the student in relation to the science educator and scientific knowledge. For example, the social aspect of meaning is reflected in how the voice of the teacher and textbook position the learner in relation to science.

Organizational/Pedagogical Aspect of Meaning

The organizational aspect of meaning focuses on the meanings communicated by the choice and sequencing of signs, attempting to answer the question: How are multimodal signs structured and sequenced to communicate conventionally assigned meanings of scientific knowledge? It includes organizational aspects as described by Lemke (1998). Additionally, in Science Education Discourse, meaning-making is also dependent on pedagogical aspects such as the structure and sequencing of multiple modalities (Jaipal, 2010). For example, how does the teacher differentiate modalities to scaffold learning for students with different language abilities? Hence, the organizational aspect of meaning will also include pedagogical aspects related to sequencing modalities for teaching and learning.

Epistemological Aspect of Meaning

The epistemological aspect of meaning involves interpretation of signs in response to the questions: How do the multimodal signs represent and communicate the nature of scientific knowledge? What do the multimodal signs communicate about valued processes and valid scientific knowledge? In the context of Science Education Discourse, Kress et al. (2001) reported that teachers communicated general epistemological meanings through particular configurations of modes. For example, teachers used empirical evidence and measurement, analogy, classification, and presentation of facts through a textbook to implicitly communicate the nature of knowledge as given fact. In other situations, teachers referred to p phenomena in everyday life, recognizing too, the Ontological nature of scientific knowledge.

Table 1. A Four-level Semiotics Analytical Framework for Interpreting Science Discourse

Aspects of Meaning	How the Sign is Interpreted
Conceptual aspect of meaning	How do the multimodal signs represent and communicate the conventionally assigned meanings of scientific knowledge
Social aspect of meaning	How do the multimodal signs position the participants in relation to each other and scientific knowledge?
Organizational/Pedagogical aspect of meaning	How are multimodal signs structured and sequenced to communicate conventionally assigned meanings of scientific knowledge?
Epistemological aspect of meaning	How do the multimodal signs represent and communicate the nature of scientific knowledge? What do the multimodal signs communicate about valued processes and valid scientific knowledge?

With regard to valued processes and valid knowledge, processes that count as valid ways of reasoning in science include deductive, inductive and abductive reasoning. Very briefly, deductive reasoning moves from the general rule to the specific application; inductive reasoning begins with observations that are specific and limited in scope, and proceeds to a generalized conclusion that is likely, but not certain, in light of accumulated evidence. Much scientific research, involving processes such as gathering evidence, seeking patterns, and forming hypotheses or theories to explain what is seen, is carried out inductively. In contrast, abductive reasoning typically begins with an incomplete set of observations (outcomes) and proceeds to the likeliest possible explanation for the set. Such reasoning yields a problematic theory explaining the causal relation among the facts (Wirth, 1998).

The Four-Level Semiotics Discourse Analysis framework for interpreting how multimodal signs represent and communicate meanings in Science Discourse is summarized in Table 1.

A Semiotics Discourse Analysis of Science Discourse

To this point, the semiotic relationship of multimodal signs, content, multiple interpretations was proposed to understand meaning making in Science Discourse. Lemke's (1998) typology of three aspects of meaning was then extended to propose a Four-Level Discourse Analysis framework that included the epistemological aspect of meaning for interpreting Science Discourse. This section addresses the following questions: Why do the signs used in Science Discourse mean what they mean? How do multimodal signs interact with each other to represent and communicate the four aspects of meaning during Science Discourse? The following two examples illustrate how the Four-Level Semiotics Discourse Analysis framework, previously outlined, can be used to interpret how multimodal signs represent and communicate meanings in the teaching of science in a Science Education setting. In particular, I will analyze how two high school physics teachers used multimodal representations/signs to represent and communicate meanings associated with the concept of inertia. Initially, the analysis contextualizes the use of the multimodal signs in relation to the social context (Science Discourse in classrooms).

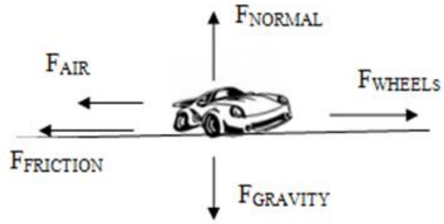
Science Discourse in science classrooms differs from Science Discourse among the scientific community in that new scientific theories are not being construed in science classrooms. In contrast, established scientific theories are used by science educators as explanatory models to explain science phenomena. While the types of signs or semiotic modalities used by scientists to represent knowledge may be similar to what science educators use in classrooms, science educators tend to select from a wide range of modalities to explain and elaborate concepts. Modalities are also selected by educators based on previous experiences implementing them with students in classrooms. Research shows that one factor, among others, affecting how modalities are selected, is teachers' views of the subject, teaching, and learning (Shulman, 1998). The two physics teacher's views were elicited from a series of qualitative interviews and supported by lesson artifacts such as lesson plans and worksheets. An analysis of each physics teacher will consider the ways they view science and learning in science and their corresponding choice of modalities to teach science. The culturally specific/conventionally assigned scientific meaning of inertia is typically reflected within a physics textbook. For the concept inertia, the scientific meaning is described by the following written definitions: Inertia is the natural tendency of an object to remain at rest or in motion at a constant speed along a straight line. Newton's first Law is described as: an object continues in a state of rest and in a state of motion at a constant speed along a straight line, unless compelled to change that state by a net force (Cutnell and Johnson, 2001).

Interpreting Multimodal Signs in Science Education Discourse: Mr. Hurd's Teaching Practice

Mr. Hurd, an experienced physics teacher, chose the following modalities to represent and communicate the concept inertia:

A. Verbal questions related to an everyday experience: "When you are going along in a car, you stop at a street sign, what happens? Why? So you are driving along and you turn a sharp corner, what happens to you? Which side do you lean to? Why?"
B. Verbal statement of Newton's Law: "Newton's first law of motion is commonly called the law of inertia: things keep doing what they always do unless something happens to change it."
C. Verbal Analogies: "People keep doing what they've always done. If you always get up at say, six o'clock in the morning, you'll get up at six o'clock in the morning. If you like to sleep in, you'll always sleep in. That's just the way you are. That's your inertia and it takes something drastic to change because you do what's comfortable for you. "What's an easy way to run?" Fast-slow, fast-slow, fast-slow or just at a moderate pace all the way? You can't run fast and then slow and then fast and then slow; it just wears you right out. But keeping at a constant even speed if you can for a longer time, you can do that because that's inertia. Your body likes to keep doing what it's doing."

D) Diagram



E) Equations $F_N + F_g = 0$ $F_W + F_A + F_f = 0$

All forces balance, velocity is constant. Motion is unchanged ⟶ inertia

Mr. Hurd had explained his view of science as “the process of understanding the physical world around you” and his role as “to develop in the kids an appreciation for the world around them and to develop in them a sense that they can solve problems.” Mr. Hurd’s intention was “to teach them [students] concepts in a way they can understand” and “to speak in a language that they can understand”. His predominant use of the verbal narrative mode related to everyday experiences to signify and communicate the meaning of ‘inertia’ appeared to be consistent with his expressed beliefs (explained below).

The *conceptual meaning* of ‘inertia’ as an object at rest is first represented through a series of verbal questions of an everyday situation experienced in a car (mode A). These questions evoke a visual image or mental picture of the abstract scientific concept in relation to the student and his or her motion in a car. The use of the word “you’re” positions students as active participants in the science phenomenon and in the meaning making process. Situating the phenomenon in a familiar, everyday experience situates scientific knowledge within student’s experiences and minimizes the *social* distance between scientist’s ways of knowing and students’ everyday ways of knowing and experiencing, portraying an image of science as being an integral aspect of students’ lives. *Pedagogical or organizational* aspects such as the use of “Why” and follow-up questions – “Which side do you lean to?” – serve to focus attention on details necessary to establish relations between objects and states of motion.

The first Law of Motion is then initially presented as a relationship between “things” and “something” (mode B). The language used is colloquial/everyday and tends to *position* scientific knowledge as accessible to students in terms of language and experience (*social meaning*). The use of the word “unless”, however, signifies and introduces the idea of a cause-effect relationship, *organizing* the stage for the introduction of formal scientific terms such as ‘force’, and supporting the construction of the *conceptual meaning* of ‘inertia’. At this stage of the sign representation, the concept of inertia has only been introduced through an example of an object at rest. The notion of an object in constant motion (a phenomena that is difficult to experience or visualize because of the presence of friction) is explained through two non-scientific analogies (mode C). These analogies of actions in everyday life illustrate the meaning of ‘inertia’ and thus serve to minimize the *social* distance between students’ experiences and the abstract science concept. Everyday words such as “keep doing”, “always done” combined with words such as “constant speed” and “takes something drastic to change" work together to emphasize the *conceptual meaning* of inertia as involving objects at constant speed or motion. *Organization* of elements in sentences such as the use of the words "but" and "because" communicate cause-effect relationships and pedagogical aspects such as repetitive sentence structures "keep doing what it's doing" reinforce the *conceptual meaning* of inertia. The analogy is then followed by a concrete diagram that illustrates the different forces acting on a car in constant motion (mode D). *Orientational* aspects of the diagram such as arrows show the direction of force and reinforce *conceptual aspects* of meaning. They also support the derivation of another sign of the concept - a mathematical equation (mode E). The mathematical equation illustrates how the different forces are related to each other quantitatively for objects in constant motion – showing the net force acting on the body is zero.

Mr. Hurd's use of the verbal explanatory narrative does however implicitly communicate a view of scientific knowledge as being a well-established, expository, cultural system of meanings; the nature of science (*epistemological meaning)* as experiential, involving processes of reasoning such as deduction, induction and abduction, is not communicated explicitly through the verbal, explanatory modalities. As well, all modalities are created by the teacher, which can be interpreted as fostering a social and power hierarchy between student and teacher and student and scientific knowledge. Multiple teacher-generated modalities in this instance place the teacher as the authority and suggest that scientific knowledge is valid and valued when communicated by the teacher and textbook rather than the student.

Interpreting Multimodal Signs in Science Education Discourse: Mrs. Lowe's Teaching Practice

Mrs. Lowe, also an experienced physics teacher, chose the following modalities to represent and communicate the science concept 'inertia'.

A. Visual images with narrative: A video entitled "Inertia" of the historical development of the concept of Inertia from Aristotle to Galileo to Newton
B. Written questions for students to answer about the contents of the video followed by a class discussion. E.g., Describe Galileo's thought experiment that led to the idea of inertia? What type of motion did Galileo think continued unless it was interrupted?
C. Demonstration: Propelling a ball out of a moving cart and the ball continues moving and lands back on the cart
D. Hands-on activity of marble on a dynamics cart with worksheet instructions and questions for students to learn about the "natural" motion of an object and qualitatively derive Newton's First Law
E. Written application questions for students followed by discussion: E.g., "What happens to you if you drive in a car around a sharp corner without reducing your speed?" "What happens to you if you are riding in a car and the driver suddenly slams on the brakes and you are not wearing a seat belt?"
F. Student generated force diagrams based on a scenario: "Draw a picture of a car at constant speed and show the forces acting on it?"

Mrs. Lowe wanted to "open up students' minds in science to new ideas and concepts and [show students] how to approach them in a scientific way – to look for evidence, to question" and to see science in the context of society. She engaged students in thinking about scientific ideas through visual, verbal, written, and action representations. Her personal beliefs about the nature of science (*epistemological aspect)* were supported by her *sequencing* of multiple modalities. A historical video (visual mode - A) about the changes in ideas about motion from Aristotle to Newton communicates the evidence-based nature of science, the changing nature of scientific beliefs over time, and the religious, social and political influences on the construction of scientific knowledge. These *epistemological aspects,* particularly the nature of scientific knowledge as changing over time and involving reasoning processes such as abduction, are reinforced by explicit written questions such as "Describe Galileo's thought experiment that led to the idea of inertia?" and "How did Newton change Galileo's Law of Inertia?" (mode B). Besides communicating the nature of science through historical examples, the video also provides representations of cases of inertia and introduces the *conceptual meaning* of inertia. Further analysis of the organization of the questions suggests that the *sequencing* of questions supports the development of the conceptual meaning of inertia. The order of questions shows the progressive historical development of inertia. Additionally, in the question "What type of motion did Galileo think continued unless it was interrupted?" the use of the word "unless" introduces the notion of a cause-effect relationship and signals the idea of a force. Another feature of the questions is the language used - academic and formal terms (e.g., proposed, motion) signal science as a formal body of knowledge that is different from everyday explanations.

Consistent with Mrs. Lowe's belief of looking for evidence, the use of a demonstration and a hands-on experiment (action modalities C and D) signal the nature of science as experiential and evidence-based and reinforce the *epistemological* aspect of meaning. However, these action representations, involving the movement of a ball on a dynamics cart, simultaneously communicate the *conceptual* meaning of inertia as an object at rest and in uniform motion. In this case, concrete and visual representations of the abstract concept 'inertia' reinforce and extend observations from the video. A worksheet, accompanying the hands-on activity, serves to organize the development of the concept of 'inertia' and the derivation of Newton's First Law. Step-by step procedures on the worksheet - *organizational* aspect of meaning - contribute to the conceptual aspect of meaning.

Once the First Law has been generalized from observation and experiment, the use of everyday applications such as the seat belt scenarios (mode E) position scientific knowledge within everyday phenomena and minimizes the gap between scientific knowledge and everyday explanations (*social aspect*). The use of the personal pronoun "you" in the scenario questions supports the *social aspect* of meaning by situating the student within the phenomena, thereby personalizing scientific knowledge. Force diagrams, the final mode (F), signal another feature contributing to the *conceptual meaning* of 'inertia' – the specific forces, their direction, and how they interact with each other. The word "draw" and "show" indicate the type of *organizational aspects* (pictures and lines of force) required to communicate the conceptual meaning of inertia on a diagram. Drawing on students' personal, everyday experience to draw a force diagram once again suggests that scientific knowledge is represented as accessible (*social meaning*) and portrayed as an integral part of everyday phenomena (*epistemological meaning).*

In Mrs. Lowe's case, modalities generated by students (diagram, written law) and a hands-on activity situate students as active participants in representing and communicating scientific meanings. Active participation in the representation of scientific knowledge tends to minimize the social and power hierarchy between students and teacher and students and scientific knowledge.

CONCLUSION

In this chapter, I applied a semiotics approach to interpret how multimodal signs signify meanings in Science Discourse. I provided research-based evidence to argue that multimodal signs or multiple semiotic modalities signify scientific knowledge. I also argued and demonstrated that in addition to the three-level typology outlined by Halliday and Lemke, a fourth aspect of meaning, the epistemological meaning, is necessary to interpret how multimodal signs signify or suggest meanings in Science Discourse. Consequently, I argued that multiple semiotic modalities in Science Discourse require interpretation in relation to four meaning aspects: conceptual, social, organizational/pedagogical, and epistemological. A Multimodal Semiotics Discourse Analysis framework incorporating the four aspects of meaning was developed and proposed as a way to provide insights into how multiple semiotic modalities represent and communicate meanings in Science Discourse. The potential usefulness of the framework was then demonstrated by analyzing the teaching strategies used by two high school physics teachers.

An analysis of the two different approaches to teaching the concept inertia in secondary school illustrates the utility of this Semiotics Discourse Analysis framework for interpreting Science Education Discourse. The use of the semiotics framework made it possible to interpret how teachers' choices and sequencing of different multimodal signs signified the four aspects of meanings in relation to scientific knowledge. For example, in the two teaching approaches, the verbal, expository modality represented science as well-established theories while concrete, visual and action modalities represented science as experiential and evidence-based.

The utility of the Framework has also been demonstrated through the detailed analysis of a biology teacher's classroom Discourse (Jaipal, 2010). These analyses suggest that a semiotics discourse analysis has the potential to reveal a teacher's tacit knowledge of pedagogy, content, and epistemology and that this knowledge can be used to help science educators reflect on their choices and sequencing of modalities, particularly in relation to the kinds of epistemological meanings communicated about the nature of science. This is particularly relevant in light of the emphasis in Science Education to educate students to make informed decisions about scientifically based societal and personal issues (Lederman, 2007).

It is important to note that this Four-Level Semiotics Discourse Analysis framework has been applied in two contexts: one, these two physics teachers' classroom practices, and two, in another study examining a biology classroom (Jaipal, 2010). The framework may be informative in several ways.

First, in these contexts there is the suggestion it has the potential to be used by researchers to understand how multimodal signs signify and represent meanings in relation to concepts and topics in different science disciplines.

Second, it may also have pedagogical implications for science educators striving to diversify instruction, solicit multiple modalities as expressions of learning, directed toward clarifying students' understandings of scientific knowledge while broadening their understandings of the nature of science.

Third, another fruitful area of investigation is the application of the Semiotics Discourse Analysis framework to other Science Discourse settings such as a research laboratory. Such an analysis may yield insights that might enhance the process of research, the communication of research findings, and the manner research can be appropriated.

Fourth, the proposed analytical framework has the potential to guide semiotics research in the Science Education field and illuminate meaning making in Science Education Discourse. Lastly and conversely, it may, as well, because of its unique application to Science Education, further the field of semiotics as suggested by considering how epistemology also conveys meaning.

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