TELLING WHAT THEY KNOW:

The role of gesture and language in children's science explanations

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Hello Justine,
Hope this is
helpful. I'd
like to receive
anything you have
that's new — and
welcome feedback.
Elaine

Abstract

What is the role of gesture in classroom science talk? This study first approaches the question generally, by asking how children communicate their knowledge of the seasons (through language, gesture and/or deictic references to props). We then ask how gestures *function* as they interplay with language in students' science talk.

A typology, coded for High or Low lexical and gestural specification, summarized how thirteen sixth graders externalized their knowledge of seasonal change . Applying it to sixteen student discourse excerpts, we tested it's usefulness as an analytical tool.

Representational gestures functioned as *redundant* to, or *enhancing* of ideas expressed through speech, or alternatively as *carriers* of scientific meaning. Findings show that gestures are an expected mode of communication in the science classroom. They can reveal student knowledge that is missing from verbal communication. Additionally, gestures may figure crucially in the construction as well as the communication of scientific insights.

1.0 Introduction

This paper explores how gesture functions in classroom science talk. Included is a discussion of how gesture patterns with language— either to support a spoken message or carry the bulk of meaning. We as researchers discovered that key contributions from some students had been overlooked in the classroom, but we did so only after repeatedly viewing students' videotaped gestures. Some students relied heavily on gesture-rich, lexically-limited expression to communicate their knowledge of science. Their comments either received no comment or were misrepresented in subsequent summaries, possibly because these children failed to foreground their unique contributions.

In researching gestures we add to existing descriptions of other discourses that fare ill in the white middle-class classroom, that is, African-American vernacular (Lemke 1990), oral traditions (Gee 1985; Scollon and Scollon 1981), and working class language patterns (Heath 1983). We argue that much more goes on in the science classroom than can be adequately communicated by words alone. Research on science talk that excludes gesture tells only part of the story. Although a student who relies too much on gestures employs a non-standard discourse by current classroom conventions, our research points to a much larger role for gesture as students make sense of phenomena. A complex interplay between gesture and language emerges in our data as a crucial characteristic of *real-time explanations* of scientific phenomenon. It is this interplay that might eventually help teachers and researchers to recognize when students are doing real scientific work, rather than mere memorization and recitation of teacher-transmitted facts.

1.1 Research Perspective on Science talk

Within the larger realm of classroom discourse (Cazden 1988), researchers have defined *science talk* as a separate register used by speakers to communicate their ideas about science. Classroom practice has fleshed out the norms for this register within the classroom. The focus in typical science classrooms is on *ideal* science talk, which models itself after the language in scientific writing, formal lecturing and scholarly presentations. Michaels and Bruce (1989) have observed the ideal at work. They described children "trying to become little scientists by adopting the practices of science as they interpreted them being manifested in their teacher's discourse and actions, and in the discourse and diagrams of their textbook" (Michaels and Bruce 1989: 3). Science talk emanating from such models values language abstractions, complicated sentences, and passive voice distancing of scientists from their work (Lemke 1990: 133).

Lemke (1990: 133-34) extracts nine such stylistic norms employed by students and teachers to judge whether remarks are scientific or not. To summarize them, verbal explicitness is essential. Teachers often fail to accept explanations if pronouns substitute for specific nouns or if deictic points plus gestures specify the referent. In science classrooms, teachers and students value technical terms over colloquial expression. Speakers in the science classroom are expected by convention to choose causal, not narrative, forms to structure their explanations. And the human hand guiding science exploration disappears in favor of an impersonal style. Lemke notes that the student must master both written and oral science talk to be taken seriously in the typical science classroom. We can not assume, however, that

established science talk *ideals* reflect the true process of *learning* or *doing* science.

Indeed, learning science through the science register may complicate the child's learning. The very features that define science talk as a formal register can make science content less accessible to students. Facts and theories, expressed in abstract and impersonal terms, can obscure content (Lemke 1990: 134). Additionally, Michaels and Bruce (1989: 7-14) expose difficulties in science textbooks which may impede understanding of existing scientific theories. The typical chapter on seasons in the elementary and secondary texts they reviewed contained a plethora of relevant terms (*axis, equator, direct* and *indirect rays*) but scant and often misleading *explanations* (Michaels and Bruce 1989: 7). One text, for example, described the earth as spinning around like a top. It then labelled this spinning *rotation*and proceeded to explain, "rotation gives us day and night" (Michaels and Bruce 1989: 8). As these researchers point out, rotation is only part of the story. A complete model of how day changes to night would represent sunlight as travelling in a straight line from a fixed sun to a spinning earth, illuminating only half of the earth at a time.

A focus on the *right way* of talking science or math can also exclude contributions made by those students having non-mainstream ways of expressing their knowledge. Michaels and Bruce (1989:19, 23) describe two children who wove personal stories into their explanations– a very 'unscientific' sounding discourse pattern. With further probing by the interviewers, these same children revealed that they *did* understand aspects of science. Their non-standard or mixed styles of science talk masked competence. For this reason, Lemke (1990: 177) recommends that teachers

learn and use the nonstandard discourse norms of their students. Rosebery et al. (1992: 2-3) encouraged the use of native-language discourse in their work with Haitian students. They reported that students acquired knowledge of the acoustic properties of drum beats by first representing distinctions through made-up symbols and traditional Haitian drumming words. Acoustic concepts which had been opaque when expressed in the science register were discovered by these students on their own.

One final problem emerges from traditional ways in which classroom cultures talk about science. The neat package of facts presented in most textbooks encourages students in their belief that 'true facts' exist, while accumulation of evidence is unnecessary. The facts are indisputable. Theories become immutable, fossilized as fact rather than presented as the fluid interface between data and 'best explanations' of the data. Newman, et al. (in press) demonstrate that even when teachers ask students to collect their own data, the data is rarely discussed theoretically. The students are left with a disparate collection of facts, which are never tied together through sense-making discussions. And when conversations do take place, the teacher may steer students toward the 'true model' currently articulated by scientists, de-emphasizing the *process* of organizing data into an explanatory model.

In summary, becoming competent in science talk is problematic. To be judged as competent, the student must talk scientifically; however, the register itself poses obstacles to learning. Its abstract language can obscure the essential meaning of established theories and concepts. Those students outside the cultural mainstream can be further excluded from active classroom participation by unfamiliarity with scientific discourse. But mastery of science talk does not necessarily translate into mastery of the scientific

process. Students who easily invoke appropriate scientific terms as they describe book-learned theories may actually mask an inability to relate data to theory.

The task of the teaching and research community is to allow students greater and more immediate access to science and its discourse. Conversation is emerging as one key to access (Lampert 1990; Spanos and Crandall 1990). Within conversation, the students' own questions can emerge, especially if the teacher consciously removes him or herself from the role as guardian of the topic (Gallas 1992: 6). Lemke stresses that the optimal conditions for learning science talk incorporate opportunities to talk within a scientifically meaningful semantic framework. He views the classroom as a forum for learning webs of scientific meaning (*thematic patterns*). Cazden (1988:134) argues that talk among peers is especially important; students can best internalize academic discourse through practice.

One further key is to allow non-standard school discourse into the classroom, as Lemke (1990: 177) suggests. Students who discuss concepts in their own terms deal first with scientific *ideas*, acquiring less familiar scientific terminology only after ideas are firmly in place. The non-standard varieties of discourse Lemke refers to include African-American vernacular and alternative discourse styles of the type mentioned by Heath (1983), Scollon and Scollon (1981), and Gee (1985), which draw on oral rather than essayist traditions. This paper will explicate an additional type of discourse traditionally not valued in school– one which relies on gestures to fill in the gaps in oral discourse.

1.1.1 Gestures in science-talk

The science discourse studies already mentioned have focused primarily on spoken or written language. Teachers and students themselves value verbal over gestural communication, as reported by Lemke in the first of a list of teacher/student definitions (1990: 133):

> Scientific language that is *correct* and *serious* so far as teachers and students are concerned must follow these stylistic norms:
> 1. Be as *verbally explicit* and *universal* as possible. This means that verbal rather than gestural or other nonverbal signs are required, and that implicit forms of grammar (e.g. use of pronouns of any kind, or ellipsis) are not fully acceptable.

Science talk *ideals* stress verbal expression. We can not assume, however, that verbal language is the best or the only tool used by children as they *learn* and *do* science. Children grappling with new understanding are often verbally unexplicit. Gestures provide an alternate window into their understanding, sometimes the only window (Newman and Crowder 1991). If gestures carry the bulk of scientific content in some students' explanations, then the student employing them violates stylistic norms known to both teachers and students. Lemke summarizes one classroom expectation for correct scientific language as follows:

> Be as *verbally explicit* and *universal* as possible. This means that verbal, rather than gestural or other nonverbal signs are required, and

that implicit forms of grammar (e.g., use of pronouns of any kind, or ellipsis) are not fully acceptable (Lemke 1989: 133).

According to traditional classroom practice, then, when students gesture, they invoke an alternative discourse pattern that may not be well-received or easily understood by their teacher and fellow students.

Beyond the communicative role of gestures, research suggests that they can figure crucially in children's construction of scientific insights. Students who appear to be actively explaining insights through scientific modeling also gesture while 'running' their models (Newman and Crowder 1991). Camp (1981: 115) suggested that gestures that adjust two dimensional representations help students predict the parameters of their model at different points in time or space.

Clement and Barowy (1980) similarly observed substantial gesturing as two naive college physics students and one expert physicist solved problems presented by the researchers. These researchers described gestures accompanying two problem solving domains– the first involving spatial transpositions and the second involving imagined forces which evoked kinesthetic visualization and muscular pushes and pulls (Clement and Barowy 1980: 17). They stated that informants gestured primarily as they *predicted outcomes* of a system's behavior (C&B 1980: 18). Typically occurring just prior to solving the problem, the gestures they observed coincided with a tendency for subjects to look away or fixate their gaze. These researchers therefore concluded that their subjects' gestures were not simply intended to communicate with the interviewer.

The above findings suggest that gestures unaccompanied by speech, in addition to language, are a natural way of representing insights, and that as such we might learn more about the discourse of science through their study. Gesture research is also emerging as a window on cognition, both within a Piagetian framework and from a Vygotskian perspective.

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Within the Piagetian framework, Church and Goldin-Meadow (1986) examined mismatches between gesture and speech during child explanations of Piagetian conservation tasks. They suggested that matched or mismatched gestures provide fundamental insights into what a child knows and how consistent he or she is in this knowledge. They characterized some children as being "discordant" (1986: 51, 67) or as having a fundamental mismatch between content expressed through gesture versus speech. Church and Goldin-Meadow subdivided their "discordant" category into three groups– instances of gesture/speech mismatches which were "less than speech", those which "complemented" speech, and those which "surpassed" speech (1986:58). They characterized all children in this category as being inconsistent in the "explanatory systems" they employ.

Church and Goldin-Meadow's use of the term "mismatches" refers to two distinct types of mismatches within the category they call "discordant". In some of their gesture/speech mismatches, gestures were congruent with speech (related meaning was expressed in both channels). Other mismatches were incongruent, they expressed opposite or unrelated meanings. For example, some children in Church and Goldin-Meadow's research who used gestures that were "less than speech" while explaining a classic conservation task, talked about the glass being tall and skinny but gesturally poured from

For C & G-M mismatches could be gst. simply portraying another aspect ?

the glass to the dish. Here there is a true mismatch between the words and accompanying gesture. These mismatched "less than speech"gestures, characterized by incongruence, parallel Cassell's (1993) use of the term *mismatched* — the gesture channel portrayed actions not matched with attributes expressed in the verbal channel. Church and Goldin-Meadow's *speech complementing* and *speech surpassing* gestures, on the other hand, differed from accompanying speech in content, but were logically congruent with verbal meaning. A coherent whole could be constructed when both channels were taken together. It is this co-construction of meaning out of gestures and language that we address in this paper.

Although Clement and Barowy (1980) do not situate their work within a Vygotskian framework, their discussion of an explicitness continuum is suggestive of that perspective. Specifically, they suggest that problem-solving gestures may be classified on a continuum of "explicitness with which actions are carried out" (1980: 11, 18). At one end of the continuum, students manipulate an actual model (actions on objects). As they move toward the other extreme of "thinking about" manipulations without actually moving, they might pantomime the manipulation of imaginary objects. This conclusion reiterates, from a gestural perspective, the process of internalization of external actions that researchers such as Leontev (in Wertsch 1985:163), Vygotsky (1962), Zinchenko (1985:105), and Wertsch and Stone (1985: 162-7) develop in their exploration of thought as action.

Researchers who are interested in gestures hold differing views of the relationship between cognition and language. Clement and Barowy explicitly state their view that the movements reported were "spontaneous results of the subject's thought process" (1985: 21), rather than communicative gestures.

like McNeill

e.g. not helpful to listener? not destined for list?

The perception of thought and language as two separate processes often theoretically unfolds as an information processing model. This view, articulated by Carroll (1986), proposes that strategies for storing, sorting, retrieving and encoding incoming information can operate without reference to language. Semantic memory is seen as "time-independent" and "context-free". It serves to match context-free representations of meaning with new input. Processing times, as dependent variables, open windows into the structure and function of the cognitive system. The system is viewed as a series of structural *memory* boxes linked by processes such as *plans* and *strategies*. Relationships between the components are essentially linear.

In an ongoing conversation among gesture researchers in the pages of *Psychological Review* (Butterworth and Hadar 1989; Feyereisen 1987; McNeill 1985, 1987, 1989), McNeill's 1989 view differs with the linear information processing analysis of the thought/language/gesture relationship, as articulated by Butterworth and Hadar (1989). The latter researchers view speaking and gesturing as separate processes, with language preceding gesture. In their view a "lexical item generates an iconic gesture through one or more of its semantic features that can be interpreted spatially" (1989: 172). As a psychолinguist, McNeill (1989:176) proposes a syncretic model of language/thought/gesture. Thinking is intimately linked with the generation of utterances, and extends throughout the spoken utterance. Gestures play an important role in this model as a means of representing syntacto-semantic chunks of information which coincide with, presage, or reiterate linear spoken meaning (McNeill 1985: 370).

To decide between these alternative models, researchers have looked for evidence, for example, that the motor systems controlling gesture and

speech are either unalterably linked in the planning phase (the *ballistic theory*) or remain open to influence from one system or the other throughout the coordinated action (*interaction theory*) (Levelt et al. 1985: 161). If gesture indeed arises out of language, as Butterworth and Hadar suggest, one would expect that language would affect gestures but that gestures would not significantly alter accompanying language during fluent speech. The evidence that Butterworth and Hadar (1989:172-3) present, however, does describe representational gestures that affect the following speech. Specifically, when a speaker pauses to retrieve words, he or she may fill the pause with an iconic gesture followed by the word.[1] The lexical meaning of the retrieval-enhancing gesture and the word it sought to elicit would presumably be similar, though Butterworth and Hadar do not describe the gestures they observed as serving a word retrieval function. If we assume that the interface between language and gesture is interactive, we would expect that gestures might at times precede speech, occurring during pauses, and furthermore, that gestures might elicit altered meanings in the following discourse. We might also expect to see examples of a gesture/language interplay that alternately negotiates or refines meaning. McNeill (1985) reports that few gestures elicited in his narrative tasks occurred during silence. Those that did consisted of beats which signal a breakdown of speech or conduit gestures which "symbolize concepts about language and communication" (1985: 354). He describes seeing stress-timing in the gestures produced by subjects as they describe a cartoon movie they have just viewed.

We propose that many of the discrepancies in timing and type of gestures that have been reported in the literature may be partly explained by the context in which the data was collected. Indeed, Riseborough (1982: 500-02)

need this for Jack

reported variations in gestures across contexts in his look at seven-year olds as they described their own play activities, told stories, or described artwork. We will describe how children used gestures, not in narratives, but in science explanations, hoping that an exploration of how their gestures functioned can begin to shed light on some of the theoretical issues mentioned above.

1.2 Research Questions

Our purpose was to establish how children in 5th/6th grade science classes *externalize* their understanding of science on the one hand, and *communicate* this understanding on the other. These two questions seem deceptively similar. However, what children externalize through their gestures may not always be communicated to others. Two main questions guided this examination:

need to look at listener's understanding →

(1) How do children externalize their scientific knowledge– through language, gestures, and/or referring to props (deixis)? Might patterns be identified and generalized into a typology?

(2) How do gestures function in their interplay with language in classroom science talk?

1.3 Curriculum Content— How seasons change

The students and teachers in this study engaged in a curriculum on seasonal change. Before describing the classrooms, students and selected lessons, it will be helpful to review the accepted theory of seasonal change. The precise mechanism regulating seasonal change is covered cursorily in elementary textbooks (Michaels and Bruce 1989:13) and often remains unknown to educated adults (Sadler 1991).[2] With the theory fresh in mind,

the reader may be better able to evaluate the accuracy of student theories presented in sections 3.0 and 4.0.

There are only two seasons on the globe at once, one season in the northern hemisphere (e.g., winter) and its opposite in the southern hemisphere (summer). The transitions between winter and summer, on the one hand, and summer and winter, on the other are what we call spring and fall respectively. Briefly, the angle with which the sun's light strikes a particular hemisphere is more acute in winter and less acute in summer (see Figure 1).This can be observed from earth in the low arc of the sun as it progresses through the winter sky compared with the higher arc of the summer sun. When the rays of the sun strike one hemisphere at a more acute angle, the energy is spread out over a greater surface area and less warming occurs. Simultaneously, that hemisphere experiences a shorter day. Winter ensues. As the angle of the sun's rays become more direct (less acute), the same amount of energy is concentrated onto a smaller surface area. The hemisphere now experiences longer days and the warmth of summer.

Insert Figure 1 here

A tilted earth lies at the heart of the conventional model for seasonal change. The earth maintains a fixed direction of tilt as it revolves around the sun (see Figure 2). This fixed tilt causes the angle of the sun's rays to vary throughout the year. Let's detail what we mean by 'fixed tilt'. If one were to thrust a spear through both south and north poles, the point of the spear would always aim toward the same spot in space throughout the earth's orbit.

This spot is identified as the north star. Referring to Figure 2., the earth begins its year on the right side of the sun, with its axis (the spear) aiming toward the star. Given this orientation, the northern hemisphere is angled *away* from the sun. The linear path of sunlight striking the northern hemisphere will have a more acute angle where it touches the earth than a similar ray of light striking the southern hemisphere. The northern hemisphere is experiencing winter.

Insert Figure 2 here

Now visualize the earth moving with fixed tilt around the sun, as in Figure 2. The axis continues to point at the north star. At a quarter revolution, neither hemisphere is angled toward the sun. Temperatures in the northern hemisphere are warming for a northern spring. As the earth continues in its orbit half-way around the sun, the fixed tilt of the earth results in the northern hemisphere being angled *toward* the sun. Drawing the line from the sun to the northern hemisphere reveals a less acute angle. The north is now in summer. At three-quarters of a revolution, again neither hemisphere is angled toward the sun. This corresponds to the fall equinox.

As can be seen, complex spatial and geometric reasoning is required to get from observation of warmer summers and colder winters to the model that explains these phenomena. Student explanations of these spatial relationships provide an ideal arena for studying gestures, since gestures often carry spatial meaning (McNeill 1985). Unlike Clement and Barowy

(1980), who associate gestures with problem solving in the domain of forces, we restrict our discussion to spatial science concepts.

2.0 Design

2.1 The Classrooms and Students

Our corpus included videotaped data from two classrooms in Hillsborough, a white, middle-class suburb of a major metropolitan area, and two classrooms located in an ethnically mixed alternative school in Riverside[3]. Four distinct classrooms were represented. One Riverside class served a combined 5th/6th grade population of 22 students taught by a single classroom teacher. In Hillsborough, two teachers in adjacent sixth grade classrooms collaborated for science activities. Our videotapes recorded jointly taught lessons with the two classes combined into a 35-student group. Major examples included in this paper were drawn from this first Riverside classroom and a combined lesson in the Hillsborough school. A second Riverside classroom was jointly taught by job-sharing teachers and retained an ethnic mix among its 16 students. While examples from this team-taught Riverside class do not appear in this paper, they are reflected in the reliability measure.

2.1.1 Lessons chosen for analysis.

During the focal lessons, students constructed models, used props, or enacted the changing earth/sun relationship as seasons progress from winter to spring, summer, and fall. Teachers in Hillsborough asked their students to physically enact the relationship between the earth and the sun, using their whole bodies. Students in the focal Riverside class used a globe to

demonstrate theories, gesturing as they did so. The team-taught Riverside class similarly used globes, but the amount of teacher regulation differed. Whereas the off-the-cuff presentations in the first Riverside class were teacher-regulated, the students themselves managed the large-class discussion in the second class.

Thirteen (13) students are represented in the current data, two of whom had multiple video performances, bringing the total number of performances to sixteen (16). Seven students and seven performances were drawn from the first Riverside class. Five students and six performances were from the combined Hillsborough classes, while one student and three performances were from the second Riverside class.

The four students from the Riverside class, whose transcripts illustrate the four categories in the typology described below, presented during a single lesson. The entire lesson occurred in the following sequence, with the students included in our examples highlighted in **bold**.

Maurice— presents a theory that places four seasons in quadrants on the globe, all occurring at the same time.

Erma— gives a highly verbal performance, arguing that only two seasons occur on the globe at once.

Gail— had originally wanted to present with Erma. Erma helps her run her model by moving the globe around the sun.

Kevin— presents ideas that at first seem similar to Gail's complex model, but ends with Maurice's seasonal quadrants.

A boy— agrees with Erma but declines to explain why.

Mallory— introduces the idea that the equator is "always warmer" and the two poles are cold, ending with Maurice's seasonal quadrants.

Mitchell— agrees with Maurice, but places seasons in four bands that do not correspond with the temperature gradient laid out by Mallory.

Allison— coordinates the temperature and band theory into a bi-hemispheric representation.

Max— argues again for only two seasons at once, using minimal words and gestures to make his point.

A final mixed performance is illustrated in this paper by a student named Chrystal from the Hillsborough class.

2.2 Method of Analysis

2.2.1 Definition of gestures

A prominent definition of speech-associated gesture proposed by McNeill in his earlier work (1985, 87, 89) limits use of "gesture" to arm and hand movements. Our definition of the gestures relevant for study goes beyond McNeill's early one. We, like McNeill (1992), have observed that children often blend manual gestures with whole-body pantomime as they comment on their own enactments of the earth-sun relationship.

Gestures considered in the current research include[4]:

(1) speech-dependent referential gestures (iconics, metaphorics) and discourse gestures (beats) (McNeill 1985, 1987, 1989)

(2) word-like or pantomimed gestures which may substitute for words within verbal syntax (McNeill 1985; Kendon 1985: 216)

(3) points to a model

(4) gestures made with the whole body

(5) meaningful manipulations of a physical model

2.2.2 Unit of analysis – the performance.

The specific question that prompted the student performances in this paper was some version of 'show us what you think causes the seasons'. A performance is defined as a child's response to a given question or speaking task posed by the teacher or another child. Additional questions, challenges or redirecting comments signal the beginning of a new performance. By definition, the length of performances varies from example to example. The performance served as the unit of analysis for isolation of four patterns of science talk.

2.3 The Typology of Language and Gestures in Science talk

We developed the typology by judging student performances along two continua:

(1) *Degree of lexical specification* of scientific content (High/Low)

(2) *Degree of gestural specification* of scientific content (High/Low)

The following matrix guided initial formulations:

Insert Table 1 here

We analyzed four best-case examples, which yielded the specific criteria in Table 2., comparing how students *lexically* specified scientific content and the degree to which their *gestures* expressed such content. The specific criteria defined more precisely the lexical and gestural behaviors associated with High and Low specification.

Insert Table 2 here

2.4 Coding of Individual Gesture-Speech Pairs

The complexity of category IV in the typology motivated a finer-grained analysis of gesture types. This analysis scored individual gesture-speech pairs (gestures and their co-occurring speech, if any) as: 1) *redundant ;* 2) *enhancing;* 3) *content-carrying,* or as one of five types of nonrepresentational gestures. It is this level of analysis that will allow us to move in the direction of discovering correlations between gestural behavior, verbal behavior, and the child's level of engagement in science as a task[5]:

(1) *Redundant* gestures are those that add no new information to that already expressed in accompanying verbal language. Many redundant gestures consisted of simple points to a prop or of gestures that precisely reproduced a content word, such as a generalized circling motion accompanying the word "around."

(2) *Enhancing* gestures extend the meaning of the language in some important way. For example, instead of a simple point while locating the hemisphere receiving direct sun rays, the child might shape a hand in a flattened 'o' position, suggesting

concentration of the sun's rays. A point might be embellished by adding an arcing motion at the end which indicates bands around the earth.

(3) *Content-carrying* gestures contain unlexicalized content. For example, the child might never mention "hemisphere", "north", "south" or "symmetrical", but gesture symmetrically with both hands, laying down temperature bands on either side of the equator, thereby revealing her knowledge of symmetrical hemispheres.

An additional five categories coded non-meaningful gestures.

(4) *Pause-filling* gestures are non-meaningful gestures (or beats) that occur during silent pauses.

(5) *Speech-filling beat* gestures are non-meaningful, discourse-related gestures that occur during speech.

(6) *Preparatory* gestures prepare a model for use, adding no meaning.

(7) *No content (other)* contains miscellaneous non-meaningful gestures.

(8) *Uncodable* contains gestures that could not be coded because they were partially off-camera. In the case of one student, however, several gestures which fail to fit other categories were temporarily placed here.

Coding of speech/gesture pairs was completed for four student performances, one from each of the four patterns of science talk. The transcripts of our four representative students were coded for the presence of

redundant, enhancing, content-carrying, pause-filling , and *speech-filling* gestures. Percentage of gesture types was computed and is reported in the *gesture analysis* sections, which follow the presentation of gesture data. Additionally, a table (Table 3) summarizes the percentage of each type of gesture found for each of four lexical/gestural patterns.

3.0 The Typology: Illustration of the Four Science Talk Categories

3.1 Type I High lexical specification -- Gestures are redundant

The first science talk category was characterized by a well-formed verbal message that could stand alone, apart from gestures. A student named Erma provides a clear example of this. She makes a clear, verbal argument for there being only two seasons on the globe at once, not four. The presence of hemispheres are crucial to her assertion. Whole-handed points reinforce the verbal message, adding no new meaning.

Examining Erma's verbal performance more closely, we note that it retains its clarity, even when stripped of gestural information. This is true mainly because she explicitly labels (or lexicalizes) all of her references to the globe. She says,

> When it's summer in the north, it's winter in the south, but I think that the closer you are to the equator, the warmer it is, no matter whether it's summer or winter. I think that when it's spring in the north, it's fall in the south. Okay ?
>
> I think that, I don't think that, there, there are like four seasons at once, I think its either summer or winter

Erma clearly refers to *north, south,* and landmarks such as the *equator,* linking seasons to specific hemispheres by name. Furthermore, she does not rely on nonspecific "here" plus a point to make her argument. Erma's gestural transcript is noteworthy for its paucity of representational gestures other than simple points:

Erma: Okay, I think, that when it's summer in the north,
gest: [hand poised] [L open hand placed on northern hemisphere]
Erma: it's winter in the south.
gest: [hand placed on southern hemisphere]
Erma: but I think that the closer you are to the equator,
gest: [pulls globe closer to self and looks at it]
Erma: the warmer it is .
no matter whether it's summer or winter.
Erma: I think that when it's spring in the north,
gest: [places L hand on north]
Erma: it's fall in the south.
gest: [places both hands on south]
Erma: Okay ?
Erma: I think that- , I I don't think that, there, there are like four
gest: [briefly and loosely flashes four fingers and rolls them into a ball]
Erma: seasons at once,
gest: [straightens four fingers]

Erma: I think its either summer,
gest: [touches northern hemisphere]
Erma: or **.

gest: [touches southern hemis.]

3.1.1 Gesture analysis

Of the nine gestures Erma produces, six (75%) deictically refer to northern or southern portions of the globe. Two gestures reinforce her assertion that *four* seasons are not present at once. She emphasizes *four* gesturally by straightening four fingers. All eight of her representational gestures are *redundant* with respect to her verbal content (8/9= 89%). One of the nine prepared the prop for use (11%).

The timing of Erma's speech drives her gestures. Each gesture coincides almost precisely with the stressed main word in the verbal line. Stress and gestures seem to be serving a similar function in Erma's performance— that of setting up the contrasts in her argument. She first contrasts *summer* in the north with *winter* in the south and her gestures coincide with her words "summer" and "winter." A similar contrast between *spring* in the north and fall in the *south* follows. Four fingers extend as she says "four" and re-emerge on the stressed "once". Gestures that are predominantly deictic and that pattern neatly with the stressed main words, as do Erma's, are not functioning in a content-carrying capacity. They are clearly redundant gestures.

3.2 Type II. Low lexical specification -- Gestures low in content

The most problematic pattern observed was that of reduced lexical *and* gestural specification. Max gives a performance low on both parameters, unfortunately so, because we will argue he had an important contribution to make. He has had his hand up during much of the Riverside lesson and finally gets to speak. At the beginning of this lesson, one boy had placed the seasons in four quadrants on the globe, creating a model that has four seasons at once. Remember that Erma argued articulately against this model, stating that there are only two seasons on the globe at once. Despite her articulateness, several subsequent presenters remained convinced that four seasons happen in four different spots on the globe.

It is into this rhetorical setting that Max offers his ideas. Max interrupts his initial remark to establish a somewhat formulaic sounding point of fact– it's always warm near the equator. This is the most lexically specified statement in his performance:

Max: I think, when, i:t's, it's always warm, near the equator.
And, when it's,.. uh, winter, up here, it's summer down here.
And there's,..... spring up here, and, fall down here. ..
Max: (very softly) I agree with Erma.
(10 sec pause without teacher remarks directed at Max.)
[Max spins Globe appearing to wait for comment]

As seen in the transcript, Max tells us little about the location of winter and summer, though we might guess by "up" and "down" that he might be contrasting the upper and lower portions of the globe. His words do little to help us distinguish spring from winter (both "up here") or fall from summer (both "down here'). His linking words "and there's" might lead us to believe that winter coexists with spring.

Examination of Max's gestures does little to clarify his meaning. Gestures were restricted to simple points that carried little auxiliary meaning. They were redundant in much the same ways as Erma's were. His index points corroborated our suspicions after the verbal-only reading that "up here" referred to the northern part of the globe, and "down here" meant the south:

Max: I think, when, i:t's:–
gest: [index pt. to globe in northern hemisphere]
M: it's: <u>always warm, near the equator</u>. (sing-song intonation)
gest: [(hard to see - back side of globe, but) top of hand glimpsed going repeatedly up and down for duration of underlined portion]
M: And,
gest: [lightly taps two fingers on globe N hemis]
M: when it's,.. uh,
gest: [lightly taps two fingers on globe N hemis]
M: winter, up here,
gest: [index pt. to N hemisphere on "winter"]
gest: [taps index twice on "here"]
M: it's summer down here.
gest: [point to S hemis]
M: And there's,.....
gest: [brings hand to chin while looking at globe]
M: (silence)

gest: [hand still on chin, looks up to left]
M: spring up here,
gest: [points to N hemis.]
M: and, fall down here. . .
gest: [points to S hemis.]
M: (silence)
gest: [L hand rests on top of tilt bar on globe, idly spins globe]
Max: (very softly) I agree with Erma.
gest: [pts. to unseen person in class, still idly spinning globe]
M: (4 sec silence)

gest: [continues to spin globe slightly back and forth]

M: **, ***?

(teacher speaks to another child then initiates another child's turn)

3.2.1 *Gesture Analysis*

Max's gestures have a greater spread than did Erma's. Whereas Erma produced mainly *redundant* gestures, Max produced *redundant gestures* (6/14 or 43%), *pause-filling beats* (4/14 or 29%), and *speech-filling beats* (2/14 or 14%). Only 1/14 (7%) of his gestures carried content. Max's gestures provide little scientific content, but they do provide non-verbal process clues which help to answer one last nagging question— why is Max putting spring in exactly the same place as winter? The following analysis of the content of Max's performance suggests a possible answer to this question.

3.2.2 *Content Analysis— what is Max saying?*

When Max pauses, puts his hand to his chin, and gazes up and to the side with his eyes, we are alerted to the possibility that he has shifted to a new segment of his theory presentation. Other researchers have noted similar connections between body shifts and the structure of discourse. For example, Cassell and McNeill (1991: 394) demonstrate that shifts in gesture type can signal a shift from one narrative level to another.

In Max's case, his reflective pause and eye movements, suggesting the use of mental imagery (Clement and Barowy 1980:19), occur exactly at the point in his narration that calls for seasonal transition and the passage of time. He first puts winter in the north and summer in the south, pauses, then places spring in the north and fall in the south. His placement parallels reality, for a northern winter really does turn to spring and a southern summer to fall. As we imagined this shift in seasons, we found Max paused about the same amount of time as we did while imagining the correct seasonal shift.

But this passage of time was only subtly marked paralinguistically and gesturally– the deictic points to northern and southern hemisphere look morphologically identical on the surface. Cassell and McNeill (1991: 396) similarly report having seen subjects point to the same location in space while attaching different meanings to each deictic gesture. In the example they report, a narrator pointed twice to the right to indicate, at the metanarrative level, a change in scene, then assigned a different meaning to the rightward point, this time on the narrative level.

Admittedly circumstantial, our evidence at least raises a doubt whether teachers or researchers can reliably infer student knowledge from underspecified on-line performances. Max sounded confused to us until after many viewings and the final deciphering of his last, quiet statement, " I agree with Erma." With this statement, Max aligns himself with Erma, who had very clearly argued the 'two season at once' theory.

3.3 Type III. Low lexical specification — Gestures high in content

In contrast to highly lexicalized performances, of which Erma's is an example, other performances relied heavily on gestures to carry meaning. Alison provides an example of this. She presents third in a sequence of four children who progressively modify the quadrant theory. A girl presenting two slots before her had identified the extreme temperature spots on the globe (cold at poles, warm at equator), but proceeded to lay down the four seasonal quadrants described by many in the class. The boy immediately preceding Alison gesturally indicated four seasonal bands. His bands did not coincide with the temperature gradient between poles and equator: fall rather than winter was at the north pole, for example.

Alison extends this band theory, coordinating it with the temperature gradient to produce symmetrical hemispheres. Her summer is at the equator, spring in two bands to either side of the equator, fall in two more bands between spring and the poles, and winter at the poles. Crucially, she communicates her notion of symmetrical hemispheres through gestures.

In the following verbal-only transcript, Alison's language is non-specific. Her description does not contain the scientific terms, such as *poles* and *equator*, that characterize Erma's science talk. She fails to name the poles and refers to the equator as "the middle", instead establishing the reference points in her model through gesture and non-specific "here." Notice also that the phrase "along here" is the only verbal clue pointing to the presence of bands in Alison's version of where seasons are placed:[6]

Alison:	(softly) because it's cold here and here. and then in the middle, as it gets— . as it comes to the middle, it gets warm.
Teacher:	yea.
Alison:	and so, here, n- along here, would be summer. And then, here, would be spring. And then . . fall, and winter.

When gestures are considered, Alison expands upon her verbal hint that seasons occur in bands. In addition to arcing gestures which suggest bands, evidence for bands rests in teacher and student comments following her presentation. The gestures accompanying the deictic references in the following passage do more than merely reiterate or enhance the verbal. They add information that is crucial to understanding Alison's message:

Alison: as it gets— . as it comes to the middle,
gest: [rigid hands start near both poles and sweep to meet each other at the equator]
Alison: it gets warm.
T: yea.
Alison: and so, here,
gest: [spread thumb and middle finger inscribe outer limits of a band on either side of the equator]
Alison: n' along here, would be summer.
gest: [holds thumb and middle finger spread while spinning globe with L hand to show extension of band around the globe at level of equator.]
Alison: And then, here,
gest: [points with middle finger of both hands to spots immediately above and below previously inscribed band for summer, then traces two (2) short lines perpendicular to and away from equator w/ both hands (indicating two symmetrical bands on either side of the equator)]
Alison: would be spring . (1.5)
gest: [at end of last gesture, traces arcs horizontally around globe (indicating two more bands adjacent to summer band)]
Alison: and then fall,
gest: [same bilateral arcing gesture repeated closer to both poles]
Alison: and winter.
gest: [bilateral arcing gesture at both poles]
Teacher: well that's similar to, the band model of Michael's * * *, * * * * *
Gail: not really. Because Michael's had one two three four. Alison has one two three.
Child: no.
Teacher: Okay, three yeah actually, . . two colds a warm and a hot.

3.3.1 Gesture analysis

The greater proportion of Alison's gestures were *content-carrying* (5/13= 39%), while 3/13 (23%) were *content enhancing*. (See Table III.-- Results of gesture coding). Only 1/13 (8%) were *redundant*. Two gestures (15%) filled pauses, while the same percentage prepared the model for use. It

is important to note that the enhancing and redundant gestures clustered toward the beginning of Alison's performance, while content-carrying ones clustered at the end (see Appendix I).

When analyzed according to discourse structure, many of Alison's enhancing gestures occurred as she was defining the parameters of her model— a model that accounts for temperature data at the equator and poles and assumes a gradual change in average temperature as one approaches the equator from the poles. In other words, they occurred as she was establishing the *setting*. Interestingly, she relied most heavily on gestures to carry her message when she argued her main point— that is, as she located the seasons within this temperature gradient. The notion of symmetrical, mirror-image hemispheres, possibly her most important contribution to the class conversation about seasons, was embedded within this main argument. This idea emerged only through content-carrying gestures.

3.3.2 Where does Alison's performance succeed and fail?

Despite having used fewer scientific terms than does Erma, Alison succeeds in communicating her continuous concept of temperature variation— "as it comes to the middle, it gets warm." Alison's use of the 'as' relative clause signals a correlation between "the middle" and *warmth*, while the notion of continuous approach in "as it comes to" combined with "it gets warm" conveys the idea of continuous temperature variation. With access to her gestures, we also understand that Alison conceives of seasonal bands which extend from the equator to at least one pole.

One of Alison's major contributions to the seasons conversation gets lost, however. We will argue that her symmetrical, bilateral hand

movements reveal that she conceives of the temperature gradient as taking place simultaneously in two hemispheres. However, Alison fails to state explicitly that she envisions two mirror-image hemispheres, nor does she comment as she simultaneously creates bands of spring, fall, and winter on *both* sides of the equator. The teacher apparently failed to notice her symmetrical movements, as did the researchers during our first few viewings. As a result, the teacher equated her model with the previously presented four-band theory.

so teacher doesn't attend to gestural info.

Alison, in using gestures to carry her understanding of hemispheres, made the teacher's evaluative task more difficult. Another student also misread her gestures, claiming that Alison had three bands in her model, while a third student got cut off by the teacher in her attempt to clarify Alison's position. Alison's gestures seem to be too subtle for reliable interpretation in the classroom environment.

3.4 Type IV. Mixed verbal specification -- Gestures high in content

In many ways, Gail's verbal-only performance parallels Erma's lexically and syntactically specified presentation. She clearly specifies the players in her model— locating the sun, the equator, the two hemispheres, and the axis. Gail also specifies spatial direction as she speaks, though being temporarily without access to her gestures, we don't know in exactly which direction. Gail tells us that the direction in which the axis points is important, and that this direction should remain constant. She locates where the most direct rays from the sun strike the earth, correcting this location from "on the equator" to below the equator.

Teacher: you would like to make an explanation ?
Gail: yeah.
Gail: well, . . I'll say that the sun is over here.

Teacher:	yeah .
Gail:	and well, if it's shining like, . . . wait I'm gonna have the axis pointing over here the whole time. The sun's over here, okay ?
	now right now:, it's— it would be shining , . . let's see. over–, right , about , straight on the equator. No , right about here. More on, the, . southern hemisphere. Shining directly about over, somewhere over here.
	So, wh— , 'cause it's like , winter , er , and , up–, it's winter in the north.
	And then, as it gets to be closer to spring , as it moves around, [to Erma] well, move it . but , okay Erma* * <move it> , it would— the sun would be more directly over the equator in spring.
Student:	(very softly) * * <like that>
Gail:	over the equator in spring, and then over here, when it's over this way, it would be summer in the north.
Gail:	but then it's still directly over here. So, as it, the closer you get to where it's directly overhead, the warmer it is.
	so when like, if it's, like, in spring the equator is the hottest place. Because, * <the sun> –, or around the equator is the hottest place, cause the sun is always pretty close there. The day length isn't very much, there.

Gail uses language to create a dynamic model in which movement accompanies seasonal change. Dynamic movement is syntactically linked to the transition between winter and spring by the word "as" in Gail's quote, "And then, as it gets to be closer to spring , as it moves around . . .the sun would be more directly over the equator in spring." By repeating her "as" phrase with slightly different content words, Gail modulates her meaning. With the first "as" we are alerted that the change to spring is a gradual process, while the second use links this change to movement. Gail employs a comparative generalization similar to Erma's ("So as it— the closer you get to where it's directly overhead, the warmer it is."). The first "it" in her generalization is linked through cohesion to the referent 'sun', albeit loosely, making this statement comparable in syntax and content to Erma's "I think that the closer you are to the equator, the warmer it is. . . ." Although Gail's verbal performance parallels Erma's lexically and syntactically specified presentation, there are some striking dissimilarities.

Some portions of Gail's verbal-only performance are easily understood, while other spots are murky. Unlike Erma, Gail's verbal performance is not smooth. Her many pauses, stops and starts coincide with gesturing. In certain places, her words are difficult to interpret without seeing the accompanying gestures. She often uses unspecified "it", only occasionally clarifying her referent ("it would, the sun would be more directly over the equator in spring"). Although Gail verbally establishes the link between seasonal change and movement, her words don't specify that the earth is moving around the sun– rotating or orbiting. The listener might easily think that spinning movement creates seasonal change. Similarly, Gail does not overtly highlight the precise earth-sun spatial relationships that produce spring and summer in the north, e.g. *The earth revolves a quarter of the way around the sun, and now the sun shines directly on the equator. This would be spring.* We could never be confident we have understood her complete message from verbal input alone.

Through gesture, Gail clarifies the underspecified sections in her verbal performance. She interweaves gestures and language to form a clear, composite picture of her understanding of the process of seasonal change. Neither modality can stand by itself. Since Gail's gestural transcript is quite long, excerpts will be quoted in the *gesture analysis* section.

3.4.1 Gesture analysis

Quantitatively, Gail produces more *enhancing* gestures than any other variety (4/56= 27%), while *content-carrying* is second at 9/56=16%. She produces a greater variety of gestures, which forced the creation of the new categories *speech-filling beat* and *no content (other)*. The 'speech-filling beat'

category encompasses beat-like gestures, similar to pause-filling beats except that they occur during speech. The 'no content- other' category is a momentary stop-gap category needed for other types of discourse gestures not characterized by up-down beat-like motions. Gail also frequently retraces her gestures. (This feature will be accounted for in future coding schemes.)

A back and forth interplay between gesture and words is evident in Gail's performance. Gestures intersperse with related verbal content to weave meaning. At times gestures may precede their verbal consequences:.

gest: *[R hand begins tracing line toward globe]*
Ga: *(silent)*
gest: *[completes line from sun to earth, heading for just below equator]*

Ga: no , right about *here.*

This is a pattern strikingly different from Erma's verbally timed gestures. The results in Table II [7] support this view. Whereas Erma never gestured during pauses, 9% (5/56) of Gail's gestures were pause-filling. There is also a sense in which Gail's gestures are helping to modulate verbal *content,* itself. In the following excerpt, Gail first states verbally that the sun would be shining straight on the equator as she models a northern winter. Her subsequent gesture causes her to revise this assertion, however:

Ga: now right now:, it's— (takes a step off camera)
Ga: it would be shining (2 sec. pause),
gest: [Loose, dangling R hand comes into view]
Ga: let's see . over-, *right , about , straight on the equator* [8]
gest: [2 beats on 'right', 'about']
Ga: (overlap with 'equator')
gest: *[R hand begins tracing line toward globe]*
Ga: *(silent)*
gest: *[completes line from sun to earth, heading for just below equator]*

Ga: no , right about *here.*
gest: [hand taps globe *a little further below equator] (2-3 inches)*
Ga: more on, the, .
gest: [brings hand back to sun on 'more' and *retraces line to globe* on 'on the']

Ga: ***southern hemisphere.***
gest: ***[touches southern hemi with back of hand]***

Unspecified "here" is clarified first by gesture and then in the verbal line ("here" —> pt. just below equator —> "more on the southern hemisphere"). Gail's verbal content changes as a consequence of her gesture. Note that each of these components adds crucial meaning— her words alone would have merely identified the southern hemisphere. In fact, Gail's words become redundant here, since her gestures have already located the relevant spot on the globe. Her gestures delineate distance from the equator, a crucial point when identifying the 'best case' example of winter. On the day that the northern hemisphere has its shortest winter day, the sun shines at its most extreme southerly point below the equator, on the Tropic of Capricorn. On the model globe, this spot is just a few inches below the equator.

One additional example illustrates how instances of verbally expressed uncertainty resolves into greater certainty as she continues gesturing. The gestures *mediate* content:

Ga: shining directly about over,
gest: [quick circular movement w/ index on 'about']
gest: [on 'over', twists hand as if turning something]
Ga: somewhere over here. . .
gest: [repeatedly circles hand with its back touching the globe on 'somewhere']
Ga: (silent)
gest: [continues with circling **but resolves hand shape into an index pt.— circles twice, then stops** before speaking again.]

Gail's uncertainty, expressed through "somewhere" and the initial backhanded circling of the hand assumes greater certainty in her follow-up gestures. The switch from backhanded indication of a general region to a more precise pointing suggests that as she continues gesturing, Gail becomes more willing to commit to the region she identifies. One wonders if such

gesturing plays a role in thinking through the spatial representations being communicated.

3.5 Types of Gestures Employed within the Larger Lexical/Gestural Patterns

When we coded and tabulated the types of gestures used by four children who expressed themselves with varying degrees of lexical/gestural specification, distinct differences emerged. Table 3 below compares the fine-grained coding of each gesture-speech pairing with the four global lexical/gestural patterns. This comparison was motivated by a desire to test whether these two levels of analysis could comparably isolate the same lexical/gestural pattern.

Results of gesture coding support the presence of four distinct lexical/gestural patterns. Note that the four bold gesture categories adequately differentiate between patterns I, II, III, and IV. The High-lexical/redundant gestures pattern is not surprisingly characterized by a high rate of redundant gestures, while the other highly lexicalized pattern (Pattern IV) features a substantial spread of gesture types, with a concentration on *enhancing, content-carrying* , and *speech-filling* gestures. Speech-filling gestures particularly capture the tendency to gesture while 'figuring things out'. The two low-lexical categories (II and III) are distinguished by a clustering of *enhancing* and *content-carrying gestures* (III), which contrasts with pattern II's tendency to include high numbers of *redundant* gestures interspersed with content-less *speech-filling* and *pause-filling* gestures.

Insert Table 3. here

3.6 A mixed performance

Embedded within actual classroom dialogue, performances may show a mixture of patterns. Often the teacher or other students work to clarify their understanding, with a resulting increase in lexical or gestural specification.

An example of this comes from the Hillsborough class. One student, Chrystal, and her teacher jointly build an increasingly clear enactment of the earth as it both revolves and spins around the sun. In the beginning, Chrystal is clearly struggling with the task. She initially underspecifies her verbal descriptions, initiating her explanation by saying "it turns around." The listener is uncertain whether Chrystal's "it" refers to earth or sun, and "around" refers ambiguously to either spin or orbit. The teacher steps in, requesting that she explain her unnarrated gestures. When Chrystal responds by verbally describing without simultaneously running the model, the teacher again protests. This time the teacher asks that she make her *gestures* more explicit. Complying with the teacher's request, Chrystal adds content to her performance– she refers to the earth's "spin." Chrystal and the teacher have jointly constructed her emerging understanding of a distinction between the earth's seasonal revolution and the spin that accounts for day and night. Chrystal has provided the content, while the teacher has encouraged clarity of expression. This student will later draw upon this co-constructed distinction to object to the preeminent theory of seasons put forth by other students in the class— a theory that summer happens as one side of the earth faces the sun, while winter occurs as it faces away.

4.0 Implications— How do gestures serve the student in the classroom?

Through this research, we hope to heighten educators' awareness of the problems inherent in science talk. The classroom conversations we have observed have dealt with emerging understanding— conceptual glimmerings that outstrip scientific vocabulary— and an urgent desire to be understood. In a fundamental way, this is science. Any scientist who has struggled to find ways of communicating complex new relationships has dealt with similar problems. Research that tackles new problems must strive to achieve common scientific meaning despite a lack of the language tools available to more mature areas of study, namely, readily available scientific terms supported by an established semantic/conceptual web. If teachers value discussion in their science classrooms, their task will be joint construction of semantic/conceptual webs. Our question is— how might the teacher promote consideration of all the students' contributions in the classroom, even those students lacking fully formed, verbally explicit science talk?

4.1 Gestures are an expected and important mode of communication in the science classroom.

Teachers who encourage the coordinating of theory and data through conversation might expect gesture to figure prominently in their classroom conversations. Gestures help many children to clarify their understanding of science, especially when the child lacks precise scientific terminology or when, as in our data, spatial relationships are involved. The children in our data who use gestures to enhance or carry their meaning are tapping their available communicative resources. Teachers need to learn such gesture talk.

By bringing both verbally and gesturally-oriented children into science discussions, the entire class acquires greater access to multiple points of view.

4.2 Gestures give insight into student knowledge that is missing from their verbal communication.

While verbally explaining spatial ideas, a child must choose precise words and connecting syntax. Children like Erma, who succeed verbally, are judged favorably by their teachers. Their answers will be picked up by the teacher, often praised. Children who don't sound so 'right' often depend on *content-carrying* gestures to convey their knowledge. Such children may be misunderstood. Their contribution to the scientific conversation may go unrecognized– uncommented upon– because gestures are less salient in the classroom, with all its distractions and various viewing angles. And if clarifying discussions are cut off, as happened with Alison, the contribution never surfaces.

Our findings echo Church and Goldin-Meadow's (1986) that the gestures of some children either surpassed (carried the content) or complemented (enhanced) their verbal explanations. They characterized children who have logical mismatches, surpassing and complementing gestures as being inconsistent, lacking a coherent explanatory system. With our emphasis on the use of language and gesture in the classroom, we prefer to tease apart their *discordant* category, proposing that both content-carrying and content-enhancing gestures can reveal a basic consistency in the underlying representational system. Children using these gestures are supplementing their partial verbal explanations with gestures that produce a coherent whole. At the level of classroom communication, however, the

particular mix of gesture to verbal may be influenced by any number of factors, including experience with school discourse, language background, ethnic norms, school activity, and personal language-learning skills or impairments. We must be careful about assigning greater value to the verbal channel in assessing whether students have coherent explanatory systems, for what may be viewed as an overreliance on gesture in one culture (American schools) may be seen as normal in another (Australian aboriginal culture, Crawford 1992). The prevailing assumption in American schools that the verbal channel is a child's primary one for conveying scientific knowledge may be inaccurate. "Saying it right" can in fact be a misleading measure of knowledge, since some kids sound good, but are really unscientific in their explanations (Newman et al. 1992). Such children may know book facts but may not have constructed the representational model necessary to think creatively, extend their knowledge, and predict outcomes given new data.

Unpolished verbal performances on the other hand, may signal that students are involved in actively constructing knowledge. If student engagement in science is valued over polished student performances, the teacher might well welcome the stops, starts, and revisions, both verbal and gestural, as evidence of such engagement. Teachers might seek to discover their students' knowledge and understand their undeveloped science talk by asking for clarification of gestures, asking verbal students to demonstrate their ideas, and encouraging lexical and gestural specification during modelling and theorizing. Allowing the scientific content in student talk to surface, whether verbal or gestural, is the starting point for further bootstrapping into more culturally-accepted ways of talking science.

4.3 Gestures may play an important role in the construction of scientific insights

The students in our fourth category who show gestural-lexical interplay have discovered a way to combine on-line explanation with a discourse style that is more easily picked up in the classroom. They use gestures to help establish relationships between parts of a model, and then translate their gestural representations into the language of the classroom.

Beyond this communicative function, the specific gesture/language relationships we have reported here support a view that gesture can reflect imagistic thought and affect subsequent language. As mentioned in the introduction, other literature suggests that students may use gestures to help them think through a model (Camp 1981; Clement & Barowy 1980). We earlier speculated that if speech and gesture truly share the same computational stage, as McNeill suggests, then we might expect to see gestures precede speech, occurring during pauses. We might further expect gestures to initiate revisions or refinement of meaning. Georgia gestures during pauses, not in an effort to recall the appropriate word, but rather as part of deciding where the sun is shining given the model that she is building and intends to run. She traces the path from sun to earth, not simply to illustrate that light goes from sun to earth, but in an effort to revise the model she is verbally and gesturally building. Gestures do much of the work in this modeling process– she revises her verbal declaration that the sun is right over the equator only after tracing then retracing the line from sun to earth. cf. Vygotsky

Teachers might be sensitized to encourage the kind of gestural/lexical interplay found in Pattern IV. This kind of interplay may be at the heart of

on-line scientific explanation, for it indicates that the child is working to build, run and revise a model rather than simply describing a memorized one. Future research will focus on teasing apart the features of this rich pattern, where gestures and language work together to modulate meaning and verbal content can be corrected by gesturally creating a working model. Such analyses will better equip us to answer our ultimate question— how can teachers recognize students doing scientific *work* as distinct from those students who are simply imitating the form of science talk?

Notes

[1]McNeill (1985: 354) notes that beats or conduit gestures, not iconic gestures, were more likely to occur during the silence associated with the breakdown of speech.

[2]Phil Sadler at the Harvard-Smithsonian Center for Astrophysics has video-taped interviews with Harvard graduates and faculty in which recent graduates and faculty alike express misconceptions about the reasons for seasonal change.

[3]Hillsborough and Riverside are pseudonyms for a town and a city in Massachusetts.

[4]Gestures excluded from current research include emblems that function as words (the OK sign) and true sign language. Although self-touches are non-representational and usually carry no scientific content, we have coded them here as a possible way to distinguish gesture-rich from gesture-impoverished performances.

[5]See Newman, Crowder, and Théberge (1992) for a discussion of three ways children engage in classroom science: by *telling a story,* by *describing a model as the right answer,* and by *running a model to do useful work.*

[6]Ashley takes up the notion, expressed by the boy who immediately preceded her, that seasons occur in bands which extend around the entire circumference of the globe. This differs from the quadrant theory, which has predominated in the class. The quadrant theory locates the seasons in four quadrants on the globe. In so doing, it neglects the role of spin in producing night and day. The band theory is distinct from the quadrant theory in that, for a given latitude, a season extends through both 'day' and 'night' on the globe.

[7]Gail's tendency to sustain gestures throughout a phrase or across several content-revising utterances forces refinements of our developing coding system.

[8]The bold italics highlight the portion of the transcript focused on in commentary above. They are not serving to mark sentence stress here.

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TABLES

	Hi Lexical specification	Lo lexical specification
Lo gestural specification	I	II
Hi gestural specification	IV	III

Table 1. Lexical and gestural specification matrix. This matrix depicts the research framework: High/Low lexical specification crossed with Low/High gestural specification. The Roman numerals correspond to the four patterns identified in the typology.

TYPOLOGY of LANGUAGE and GESTURES in SCIENCE TALK

I. **High lexical specification**	— **gestures low or redundant in content**
• abundance of content words used appropriately in context	• infrequent use of representational gestures
• logical relationships marked syntactically	• use of simple points or representational gestures that add little new meaning
• lexical line can stand by itself	• gestures coincide with main lexical items, especially those stressed in phrases
II. **Low lexical specification**	— **gestures low in content**
• logical relationships not marked syntactically - often implied	• infrequent use of representational gestures
• predominance of unspecified deictic words	• gestures add little new meaning (mainly *redundant*, sometimes *enhanced*)
• content words may be used rotely at times (sing-song recitation, task-avoidance)	• use of simple, unelaborated points
III. **Low lexical specification**	— **gestures high in content**
• logical relationships not marked in syntax - often implied	• frequent use of representational gestures • gestures *carry* unstated meaning
• predominance of unspecified deictic words (here, this, it)	• pointing has representational elements that enhance meaning • timing of gestures not strictly tied to lexical items.
IV. **Mixed verbal specification**	— **gestures high in content**
• lexicon/gestures interdependent	• frequent use of representational gestures
• lex/gest complement each other to modulate meaning	• expect *content enhancing* and some*content - carrying* representational gestures.
• mixed lexical specification	• when lexicon underspecified, gesture clarifies
• talk influenced by gestures	• gestures often precede related talk rather than precisely coinciding with related content words
• partial or full repetition of content	• immediate repetition or retracing of gestures

Table 2. A typology of the linguistic features and gesture types which pattern as four separate ways of talking during science explanations.

	Lexical/gestural pattern			
	I	II	III	IV
type of gesture				
Preparatory=	11%	0%	15%	7%
Redundant=	**89%**	**43%**	8%	9%
Enhancing=	0%	0%	**23%**	**27%**
Content Carrying=	0%	7%	**39%**	**16%**
Pause Filling=	0%	**29%**	15%	9%
Speech Filling (beat)=		**14%**		**13%**
No content (other)=				5%
Uncodable=	0%	7%	0%	14%
	100%	100%	100%	100%

Table 3. Results of gesture coding: Number of gesture types /total gestures (expressed as a percentage) in the four performances, which serve as exemplars of each lexical/gesture pattern: **I. High lexical specification, gestures low or redundant in content ; II. Low lexical specification, gestures low in content; III. Low lexical specification, gestures high in content; and IV. Mixed verbal specification, gestures high in content.**

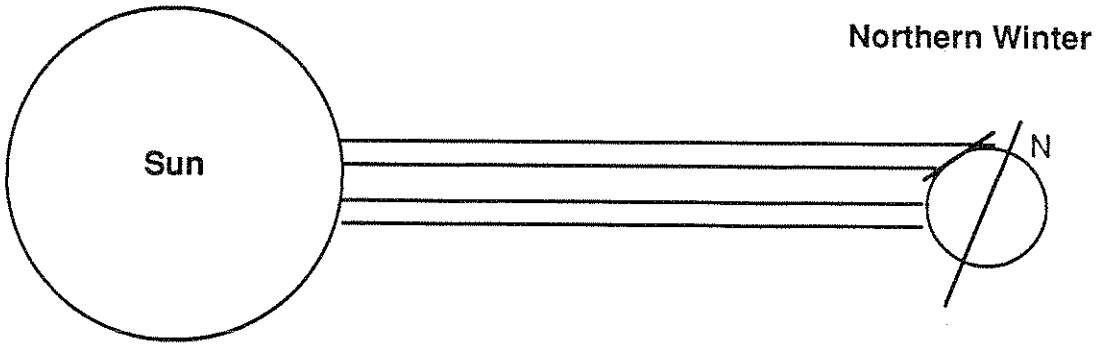

Figure 1. Mechanism for Seasonal Change: During a northern winter, the earth's tilt causes the same amount of sunlight to spread over more area in the northern hemisphere than in the south. This means that the same amount of energy must heat a larger surface, with the net result being cooler weather– winter.

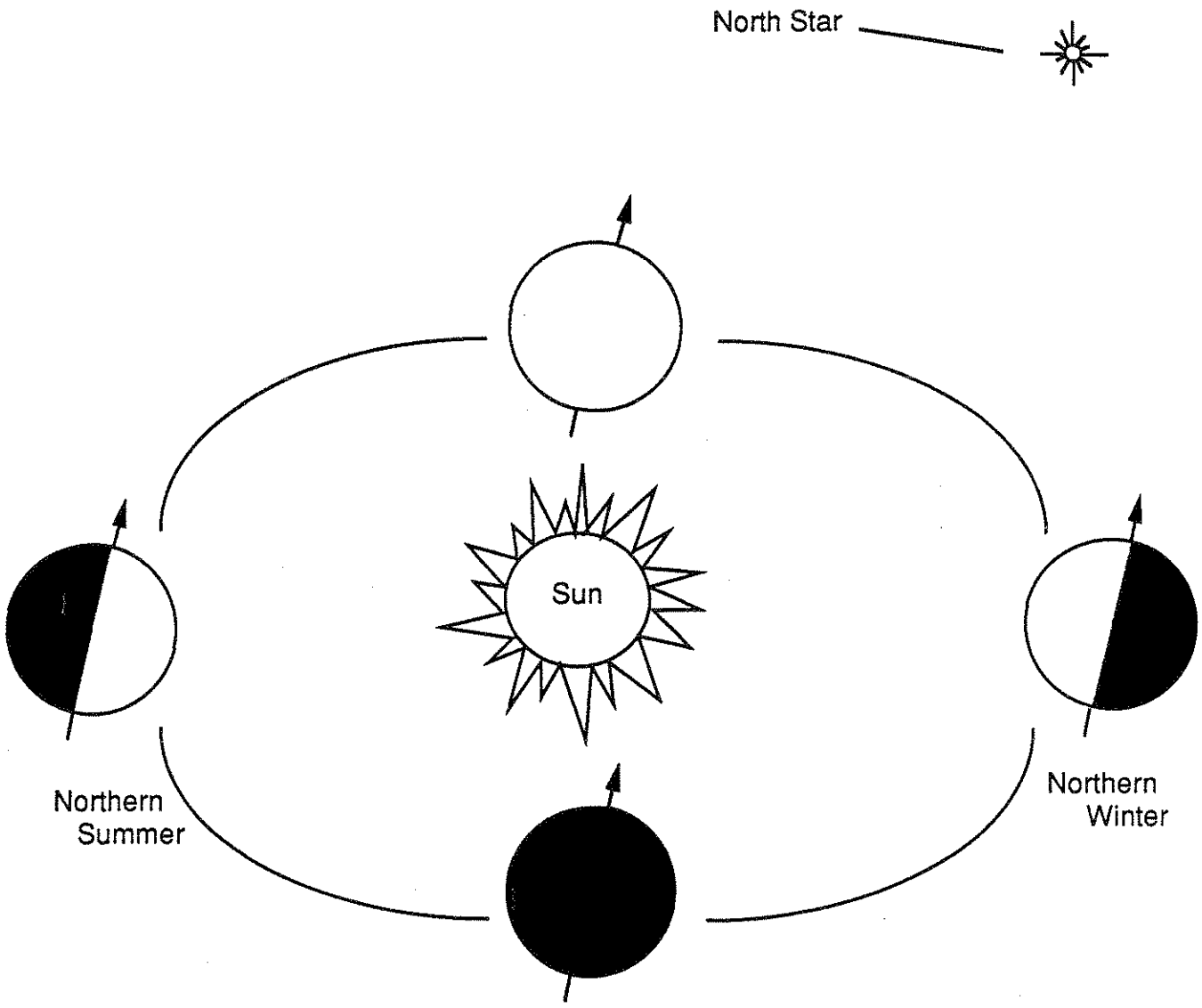

Figure 2. Model of Seasonal change: The earth maintains a fixed tilt throughout its orbit around the sun. When the northern hemisphere is angled away from the sun, winter results.