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ABSTRACT

High among the many purposes of education is the conjecture that higher-levels of cognitive activity are important to learning and intellectual development. One of the most exciting educational implications is the leverage that one may expect by enhancing learning at the cognitive and metacognitive levels. Despite the relatively rich history in both cognition and metacognition, no consensus has emerged as to the nature of higher-level knowledge. The present study aimed to know more about: (1) the nature of metacognition, and to characterize facets of higher-level metacognitive thought; (2) the process by which individuals change their metacognitive capacities with experience; and (3) the role of pedagogical practices in facilitating changes in metacognition. Six cohorts of elementary students (grades 1-6 participated in this naturalistic study across three academic years. Analysis of the data supports the following claims. First, metacognition is within the capabilities of young (school age) children. Second, children's metacognitive ability is multifaceted in nature, it can be probed and teased apart. Third, changes in metacognitive sophistication can be gained by actively engaging in the process. Fourth, changes in metacognitive ability and conceptual understanding may be more closely linked to the individual student's epistemological stance. (Contains 102 references.) (Author)

Probing the Dimensions of Metacognition:

Implications for Conceptual Change Teaching-Learning

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Abstract

High among the many purposes of education is the conjecture that higher-levels of cognitive activity are important to learning and intellectual development. One of the most exciting educational implications is the leverage that one may expect by enhancing learning at the cognitive and metacognitive levels. Despite the relatively rich history in both cognition and metacognition, no consensus has emerged as to the nature of higher-level knowledge. The present study aimed to know more about: (1) the nature of metacognition, and to characterize facets of higher-level metacognitive thought; (2) the process by which individuals change their metacognitive capacities with experience; and (3) the role of pedagogical practices in facilitating changes in metacognition. Six cohorts of elementary students (grades 1-6 participated in this naturalistic study across three academic years. Analysis of the data supports the following claims. First, metacognition is within the capabilities of young (school age) children. Second, childrenſs metacognitive ability is multifaceted in natureóit can be probed and teased apart. Third, changes in metacognitive sophistication can be gained by actively engaging in the process. Fourth, changes in metacognitive ability and conceptual understanding may be more closely linked to the individual studentſs epistemological stance.

Introduction

High among the many purposes of education is the conjecture that higher-levels of cognitive activity are important to learning and intellectual development. There seems to be two components to this goal, one to do with cognition (viz., problem solving, heuristic, planning) and the other to do with metacognition (viz., knowing that one knows). The two parts are closely related, because during intellectual development one sees the acquisition of not only traditional subject matter and related skills but also a more general knowledge that seems to be useful across a broader, subject-independent domain. To varying degrees, one can consider the result of these higher level cognitive activities as intellectual functioning and knowledge development. Thus, cognition is about organizing one's own intellectual resources efficiently and metacognition is about what one knows about his or own thinking or thinking processes (Flavell, 1976). One of the most exciting educational implications is the leverage that one may expect by enhancing learning at the cognitive and metacognitive levels.

There is an increased interest in the science education community to teach for "understanding." Smith, Blakeslee, and Anderson (1993) have claimed that meaningful learning in science involves coming to understand scientific conceptual schemes as they are used to describe, explain, or make predictions about the natural world. They went on to argue that traditional approaches to science instruction and curriculum content consisting of formal definitions for concepts, equations and formulas, and practice in applying these formulas to straightforward problems seldom encourage the learners to reason qualitatively about conceptual relations.

Theoretical models which describe learning as an active process in which learners become aware of and reason about conceptual relations or describe learning as a process of conceptual refinement has been called *conceptual change*. Starting from their own common sense ideas, learners go through a process of conceptual change by refining their own intuitions about the physical world through organizing, reorganizing, or replacing existing conceptual relations. Baird, Fensham, Gunstone, & White (1991) have argued that engaging in metacognitive reflections can enhance conceptual change. They have inferred that one reasons for the lack of success in attempts to bring about conceptual change is that the strategies employed during the teaching-learning process pay insufficient attention to assisting the learner to become metacognitive in order for them to control the nature and direction of change.

Despite the relatively rich research history in both cognition and metacognition, no consensus has emerged as to the nature of higher-level knowledge. My intent within this paper is twofold. First, to describe a class of higher-level knowledge associated with the process of metacognition. The class is higher-level in that it is knowledge about science knowledge rather than science content per se. Second, to argue for a transparent link between metacognition and conceptual change learning as the underpinnings that support conceptual understanding in science. My claim is that students, when given the opportunity, can engage in discourse about their thinking. Furthermore, the type of metacognitive discourse students engage in is varied. I believe it is fair to say that no compelling analysis and evidence has been offered to show exactly how varied higher-level metacognitive discourse can be, nor has there been a convincing demonstration of the general value of teaching to these levels.

In this paper, I first briefly consider the literature that has served as a conceptual underpinning for this work. Second, I describe the work of Project META (Metacognitive Enhancing Teaching Activities) and some general principles of the project are outlined. Then, I describe the methods underlying one component of the research: the delineation of the range of metacognitive capabilities of young children. Next, I illustrate the analytical process in some detail using metaconceptual discourse of several elementary age children. Finally, I discuss the educational value and implications for further research.

Theoretical Framework

During the past two decades, researchers in philosophy of science, cognitive psychology, and science education have begun to elucidate some fundamental understanding of the dynamic role of the learner in developing conceptual knowledge and engaging in higher-level cognitive activity. Until recently, these communities worked almost entirely exclusive of each other (Ennis, 1979; Duschl, 1985). With the current resurgence of epistemological interests in both the science education and the cognitive psychology community (Duschl & Hamilton, 1992) questions concerned with, albeit in different ways, the nature of science and science teaching have emerged. This epistemological turn is evidenced in the significant increase in academic activity and research that has had important implications for approaches to science teaching and learning.

Different bodies of research from major fields of theory and practice have informed this study. One field has dealt with the importance of understanding the nature of students' conceptualizations of natural phenomena in order to teach fruitfully (Helm & Novak, 1983; Driver, Guesne, & Tiberghien, 1985; Osborne & Freyberg, 1985; Novak, 1987; West & Pines, 1985; Pfundt & Duit; 1991; and Duit, Goldberg, & Niedderer, 1992). A second has focused on the power of an underlying constructivist epistemology to influence students' understanding and learning in science (Magoon, 1977; Resnick, 1983; Strike, 1987; von Glasersfeld, 1989, 1992). A third has pointed to the need to consider learning as an active structuring and restructuring process requiring cognitive changes of different kinds. Namely, conceptual change learning involves *both* building conceptions of new experiences in relation to past experiences and modifying conceptions which may be at variance with the canonical explanations of natural phenomena (Posner, Strike, Hewson & Gertzog, 1982; Hewson, 1981, 1982; Carey, 1985; White & Gunstone, 1989; Dykstra, 1992; Scott, Asoko, & Driver, 1992). A fourth has described the significant role metacognition plays in illuminating the nature of students' conceptions in science domains (White, 1986; Baird, 1986; White & Gunstone, 1989; Hewson & Thorley, 1989; Thorley, 1990; Baird, Fensham, Gunstone, & White, 1991; Gunstone, 1992; Hennessey, 1991b; Beeth, 1993; Hennessey & Beeth, 1993). The work described in this paper illustrates how closely these four theoretical fields were interwoven to provide a theoretical framework underpinning this study.

Students' Conceptions of Natural Phenomena

An early article by Hall and Brown (1903) and a review by Oakes (1947) have provided evidence that research on studentſ conceptions of natural phenomena has had a long history. More recent reviews of relevant studies have been provided by Driver and Easley (1978); Gilbert and Watts (1983); Driver and Erickson (1983); Confrey (1990); Duit (1993); and Wandersee, Mintes, and Novak (1993). Carmichael, Driver, Holding, Phillips, Twigger, and Watts (1990), and Pfundt and Duit (1994) have provided bibliographies devoted to students' conceptions in science. An analysis of this literature base has revealed an initial research focus on identifying and quantifying students' conceptions of science principles and concepts. Briefly, these studies have provided ample evidence that students frequently held conceptions in many fields that were substantially different from the scientific concepts taught in school (Helm & Novak, 1983; Novak, 1987). Some, but certainly not all of the non-canonical conceptions were shown to inhibit understanding and learning of certain science concepts, proved to be highly resistant to change, and frequently persisted even after what was considered to be good traditional instruction (Champagne, Klopfer, & Gunstone, 1982; Champagne, Gunstone, & Klopfer, 1985). Further investigations were conducted on ways to modify students' non-canonical understandings and beliefs. When this led to limited success researchers extended the scope of their investigations to include students' and teachers' beliefs about the nature of science, as well as their beliefs about learning and teaching. As a result of this extension, researchers have begun to elucidate: (a) people's epistemologies in general (Kuhn, Amsel, & O'Loughlin, 1988); (b) teachers' beliefs and epistemological commitments (Hewson & Hewson, 1988, 1989; Tobin, 1990; Hewson, Kerby, & Cook, 1995, Hewson, Beeth & Thorley, 1998); (c) students' views about the nature of scientific knowledge (Nadeau & Desautels, 1984; Carey, Evan, Honda, Jay, & Unger, 1989; Carey & Smith, 1993; Songer & Linn, 1991); and (d) the interactions between epistemological commitments of students and those of their teacher or the curriculum (Schommer, M, 1994, 1997; Roth & Roychoudhury, 1994; Hammer, 1995; Davis, 1997; Hofer & Pintrich, 1997; Haslam & Gunstone, 1998). Taken as a whole, the above-mentioned collection of investigations emphasizes the importance of considering the epistemological assumptions underpinning classroom learning environments.

Constructivism

"Constructivism" is, as formulated by philosophers, cognitive psychologists, and educational researchers open to different interpretations. Regardless of the diversity of views about constructivism's underlying assumptions (Strike, 1987; Vygotsky, 1986; von Glasersfeld, 1987,1992; Driver, 1983, 1989; Driver & Bell, 1986; Guba & Lincoln, 1989; Suchting, 1992; Matthews, 1992, 1992b, 1993; Good, 1993; Solomon, 1994) there is not doubt that, during the past two decades, constructivism has had a major influenced on both research and practice in science education and elsewhere. Both proponents and critics of constructivism have centered their arguments on three main issues. *First* , various positions on the nature of reality have been called into question. Constructivists have posited that reality exists independent from cognizing beings, but hold direct access to this reality is illusive. Critics, on the other hand, have claimed that constructivism is ontologically flawed as it denies the existence of physical world order. *Second* , various positions surrounding the nature of knowledge and knowledge production has generated much discussion. Proponents of constructivism have claimed that knowledge construction is an interpretive process, new information is given meaning in relationship to a person's prior knowledge. In addition, Hewson, Kerby, and Cook (1995) have posited that knowledge construction is not to be viewed as idiosyncratic or composed of completely personal constructs because social agreements about meaning tend to limit how new experiences are interpreted or perceived in any given situation. Thus, from a constructivist perspective, knowledge is seen as situate, extending beyond the individual's construction of subjective knowledge, to acknowledge the central roles of language, culture, motivation, social setting, and physical contexts. Critics, in turn, have claimed that the constructivist position is epistemologically flawed. The foci of their arguments have centered on the role of sense impressions and experiences during learning coupled with a concern for an excess focus on the individual which does not take social issues into consideration (Solomon, 1994). *Third* , positions surrounding the philosophical underpinnings of constructivism have emerged for discussion. What appears to be argued vigorously is the relationship between empiricism and constructivism. Both proponents and critics have evoked aspects of history and philosophy of science to support their claims about nature of constructivism. Further elaboration of the nature of constructivism is needed; not so much to defend its ontological and epistemological value but to save the power constructivism has to offer when serving as an underlying base for validating a genuinely emancipatory form of pedagogy.

Conceptual Change

Development of a solid base of knowledge about both students conceptions and the nature of knowledge production have been instrumental in providing a framework for considering the learning process involved in changing learners' conceptions, as well as providing a framework for considering pedagogical issues that facilitate those changes. As a result, a family of learning models, termed conceptual change models of learning, has been designed. Each model (a) recognize the importance of students' underlying conceptions of science and how those conceptions might influence their learning; (b) consider knowledge and intellectual development more that an accumulation of bits of information; and (c) describe learning as a dynamic process requiring changes of different kinds.

To date, there has been no consensus within the research community about how best to describe this process of conceptual change. The ensuing discussions have centered on a number of issues that are germane to teaching and learning. Namely, how best to describe:

- that which is changing: such as, the nature of concepts (White & Gunstone, 1989), concept/conceptions distinction (Dykstra, 1992), facets of student knowledge (Minstrell, 1992);
- the character of changes that take place in learners conceptions over time: that is, weak knowledge restructuring/strong knowledge restructuring (Carey, 1985), principle or belief changes (White & Gunstone, 1989), accommodation/assimilation (Posner, *et al.* , 1982), conceptual capture/conceptual exchange (Hewson, 1981);
- the initiating factors of conceptual change: such as, disequilibration (Dykstra, 1992) dissatisfaction (Posner, *et al.*, 1982), cognitive conflict (Scott, Asoko, & Driver, 1992); and
- the relative status (intelligibility, plausibility, and fruitfulness) a learner gives to a conception (Hewson, 1981, Hewson & Thorley, 1989; Thorley, 1990; Hennessey, 1991, 1991b; Hewson & Hewson, 1992; Treagust, Venville, Harrison, & Tyson, 1997).

Likewise, in the process of delineating these unique differences, no consensus within the research community has emerged to claim that one view of conceptual change is a more powerful way of characterizing the nature of change in a learner's knowledge state.

The work in this study uses a model of learning as conceptual change initially articulated by Posner, *et al.* (1982) and further elaborated on in subsequent articles (Hewson 1981, 1982; Strike & Posner, 1985, 1992; Hewson & Thorley, 1989; Thorley, 1990; Hewson & Hewson, 1992; Hewson, Beeth & Thorley, 1996). The central concepts of the model are *status* and *conceptual ecology* . Hewson and Hewson (1992) have succinctly delineated the central notions of status. Briefly, they have indicated that an idea's intelligibility, plausibility, and fruitfulness to a person determine the status an idea has for a person holding it. Likewise, they have claimed that the degree to which a person understands, accepts, and finds an idea useful the higher is its status. The model predicts that conceptual changes do not occur without concomitant changes in status. Hewson, Beeth, and Thorley (1998) have summarized conceptual ecology as dealing with:

> all the knowledge a person holds, recognizes that it consists of different kinds, focuses attention on the interactions within this knowledge base, and identifies the role that these interactions play in defining niches that support some ideas (raise their status) and discourage others (reduce their status). Learning something, then, means the learner has raised its status within the context of his or her conceptual ecology.

Hewson and Hennessey (1992) have suggested that making the status of learners' conceptions explicit should be an integral part of the teaching-learning process. Furthermore, they have provided evidence that within limits, learners can use technical language (intelligibility, plausibility, and fruitfulness) of the conceptual change model to determine the status of their own conceptions.

Metacognition

The term metacognition has had a history of variable interpretations within the literature. For Flavell (1976), metacognition refers to:

> one's knowledge concerning one's own cognitive processes and products or anything related to them...Metacognition refers, among other things, to the active monitoring and consequent regulation and orchestration of theses processes in relation to the cognitive objects or data on which they bear... (p. 232).

Brown (1978) has defined metacognition as "knowing about knowing." She has summarized metacognitive activities under two distinct but conceptually related categories--activities that are concerned with (a) conscious reflection on one's cognitive abilities and (b) self-regulatory mechanisms during on-going attempts to learn or solve problems. Brown's two categories differentiate between what people know about their thinking processes and the application of a set of heuristic as an effective device for helping people organize their methods of attack on problems in general. Thorley (1990) has employed a conceptually different distinction using the term "metacognitive" to refer to reflections on one's own thinking and "metaconceptual" to refer to reflections on the content of the conceptions themselves. Kuhn, *et al.*, (1988) have noted that the key aspect of metacognitive operations entails "conscious awareness:"

> Ö. the ability to think about a theory rather than only with it. In the later case, a person uses theories as a means of organizing and interpreting experiences but is not aware of their existence (p. 219).

In other words, people are metacognitive when they make their own thoughts "objects of cognition" (Kuhn, *et al.*, 1988). Baird, Fensham, Gunstone, & White (1991) have described metacognition as:

> a person's *knowledge* of the nature of learning, effective learning strategies, and his/her own learning strengths and weaknesses; *awareness* of the nature and progress of the current learning task (i.e. what you are doing and why you are doing it); and *control* over learning through informed and purposeful decisions making (p. 164).

Each of Baird *et al's* assertions has touched on specific learning strategies: processing, evaluating the processing, and deciding. Lastly, White (1989) has contended that whatever facets of metacognition a researcher chooses to include or exclude in the definition of the term, metacognition in and of itself refers to an inner process not an overt behavior (i.e., an inner awareness of one's own unobservable constructs). White has further delineated the problems associated with assessing the ability of an individual to be metacognitive as the task of making inferences about the unobservable (awareness of inner constructs) from observable overt performances (verbal discourse, writing, use of illustrations).

The above cursory review of the literature illustrates the multidimensional character of the term metacognition. Metacognition is characterized as: (1) an awareness of one's own thinking; (2) an awareness of the content of one's conceptions; (3) an active monitoring of one's cognitive processes;

(4) an attempt to regulate one's cognitive processes in relationship to further learning; and (5) an application of a set of heuristic as an effective device for helping people organize their methods of attack on problems in general. Because of the multiple definitions associated with the term metacognition, it has become imperative that I clearly delineate how the term metacognition is used in this study. The work described in this paper is based on a particular view of metacognition. Specific examples of what is include and excluded from this view and the rationale supporting the exclusions, are elaborated in the section on Project META.

Inherent within the process of conceptual change is the understanding that a learner needs to be metacognitive in order to go through a conceptual change process (Gunstone, 1992, 1994; Baird, *et al*, 1991). Although it is clear that research has recognized the relationship between metacognition and conceptual change, a comparably detailed base of knowledge about variations within metacognitive discourse does not exist. Yet such knowledge is fundamental to design teaching-learning strategies that can successively enhance an individual's ability to be metacognitive. The work reported here provides an important link in the chain of knowledge. It moves beyond current descriptions of reflections on how to remember and choose appropriate monitoring strategies *to* reflections on the content and status of one's conceptions and the ability to evaluate the consistency and generalizability inherent in one's conceptions.

Project META

In this section, I briefly describe Project META (Metacognitive Enhancing Teaching Activities) and the classroom setting in which the study was conducted. I then describe how the above mentioned literature base was used as the basis for a system of instruction designed to promote metacognition within a classroom setting and to provide data in the form of higher-level metacognitive discourse.

Nature of Project

Project META is a three-year naturalistic case study of the process of metacognition through individual and group discourse. At present, there is a lack of interpretive studies on the higher-level metacognitive activity and even a greater paucity of research on the role metacognition plays in facilitating conceptual development. Three major aims of Project META were:

1. Nature of metacognition

   To know more about the nature of metacognition, and to characterize facets of higher-level metacognitive thought.

2. Changes in metacognition

   To know more about the process by which individuals change their metacognitive capabilities with experience. Particularly to explore the effect of change whereby students assume greater personal awareness and control over thinking about their own thinking.

3. Facilitating change

   To know more about the role of appropriate and productive pedagogical practices for facilitating changes in metacognition. Particularly, to explore the role metacognition plays in facilitating changes in students' conceptual understanding.

Classroom Setting

The classroom in which this study was conducted was situated in a parochial elementary school (SAS) with one section per grade level and an approximate enrollment of 170 students in Grades Pre-K through 6. The school is located in a rural community adjacent to U.S. Midwestern capital city (population approximately 200,000). It is a coeducational school, with a largely white and middle-class student population.

Six cohorts of students (all the students in grades 1 though 6; ages 6 though 12) participated in the study. The various cohorts had essentially remained intact over the period of their K-6 education. During Project META, each cohort of students was followed across three academic years.

Instruction

The academic instruction at SAS was departmentalized, that is, the faculty specialized in specific content areas--reading and language arts, math, science, social studies, music and art. I have served as the science specialist at this educational facility for over 20 years. As is turned out, having students in my science courses for a period of six years afforded me an unprecedented and useful view into the natural function of their epistemologies and content specific knowledge domains. In addition to a long-term relationship with the students enrolled at SAS, the symbiotic relationship between my research and practice proved to be an integral component of Project META. During this study, research was not distinct from practice. Implementation of research finding to classroom practice proved to be a mote issue because it occurred simultaneously with and was synonymous with the generation of knowledge and understanding gained from the research.

For this study, content specific units were designed to explicitly stimulate classroom interactions that focused on the students' conceptions of science content, the nature of science, the nature of knowledge production and learning, and the nature of explanatory models in science. Throughout the course of the study, all six cohorts of students participated in general activities designed to give them experiences at considering their own thinking and knowledge claims; that is, activities that were designed to stimulate metacognitive reflections. To provide a clearer picture of the classroom context underpinning this study, a description of the general teaching-learning activities used to support metacognitive discussions is included in the following section.

General Activities Employed to Enhance Metacognition

Throughout this study, three general learning actives served to enhance student metacognition. First, the students at all grade levels used *poster productions* . The purpose of this activity was to obtain information about the conceptions[1] each student (or group of students) held or were currently considering about the phenomena under investigation. Both small group and large group discussions about the content of the posters often provided insights into the reasoning various students employed to support their constructs. Without this information, it would be impossible for me to provide meaningful analogies, metaphors, anomalies, discrepant events, bridging analogies, or laboratory activities to argument or challenge student thinking. Second, *conceptual models* (in the form of diagrams, three-dimensional physical models, or concept maps) were designed by the students to help represent their conceptual frameworks. No attempt was made to teach the "accepted" canonical view during or following conceptual model development. Rather, through individual dialogue and group discussion, the students were encouraged to use their models to make some predictions about a new but closely related phenomena. It was usually at this point that the various models' lack of generalizability or explanatory power began to emerge. Encouragement from me to look for more consistency lead to further model revision. Lastly, the use of *technology* in the form of word-processing, computer-based graphic programs, student generated audio and video recordings and the use of transcribing machines, provided additional mechanisms to help the students capture their thoughts about the issues being discussed. All students (grades 1 through 6) adopted these strategies in various forms as they worked through the three-year course of this study. Some students expended considerable energies producing and discussing the content of their various posters; others concentrated in developing representations in the form of conceptual models, while others concentrated on audio/video recording discussions with peers or word-processing their individual thoughts.

A System of Instructional Design

As noted in the theoretical framework section of this paper, a number of recent models of conceptual change have been developed that describe conditions necessary for conceptual understanding to occur. These are cognitive conditions, necessary for developing minimal to full understanding of a new conception. As cognitive conditions they do not define directly what teachers or students should do to develop an understanding of science and science content. They can, however, serve as criteria by which science teaching and learning can be evaluated. If students are to engage successfully in conceptual understanding of science content, then, both teachers and students need to meet each of the cognitive criteria described in conceptual change models of learning. Likewise, a number of recent research studies have suggested teaching strategies that promote conceptual change. Each set of strategies relates in some general, commonsense way to the conditions for conceptual change described in the various conceptual change learning models. In all of these suggested teaching strategies, the role of the teacher is an especially active one. Beeth, (1993b) one the other hand, has described not only the importance of considering the role of the teacher, but also the importance of considering the role of the students, the role of the teacher-assigned learning activities, and the role of the type of assessment employed during conceptual change learning.

During Project META, I sought to *integrate* the cognitive conditions of the model of conceptual change (Posner, *et al.* 1982) and the recommendations of several cohorts of researchers (viz., teaching strategies that promote conceptual change) with the dynamic roles of teacher, students, activities, and assessment respectively. In doing so, an integrated set of goals and teacher-student expectations were developed to serve as an underpinning for Project META.

Another important aspect underpinning the development of Project META was the need to develop a workable definition of the term metacognition. As noted earlier, the term metacognition has been frequently employed in the research literature in broad and variable ways. Thus it becomes imperative, for purposes of clarification, to describe how the term metacognition is used in this study. In the sections below, both the term metacognition and the educational goals serving as a theoretical framework for Project META are outlined.

Metacognition as Defined in Project META

My current thinking about the term metacognition is derived, in part, from the multidimensional character of metacognition as described in the literature; and, in part, from over fifteen years of experience at promoting and monitoring the metacognitive capabilities of learners (ages 6-12) within the context of teaching-learning science. When synthesized into a conceptual whole, and combined with the conviction that metacognition is inherent in the process of conceptual understanding, the following picture emerges. In this study, metacognition refers to a learner's ability to:

1. Consider the basis of one's beliefs in a specific conception;
2. Temporarily bracket, or set aside, one's conceptions in order to assess competing conceptions;
3. Consider the relationship between one's conceptions and any evidence that might or might not support those conceptions;
4. Consider explicitly the status of one's own conceptions; and
5. Evaluate the consistency and generalizability inherent in one's conceptions.

Excluded from this particular view of metacognition is the ability to (a) execute a sequence of strategies, (b) employ a set of heuristic that lead to success on a task, and (c) explicitly self-regulate one's behavior in the midst of performing complex tasks. Specific examples of what is excluded from this characterization are:

1. Learning strategies: the ability to make inferences, check for understanding, summarize or paraphrase text, recognize contradictions or ambiguities in text, re-inspect text, generalize, resolve comprehension difficulties, develop or assess a set of learning goals for an activity;
2. Heuristic: initial description and analysis of a problem to bring it into a form needed to facilitate its subsequent solution, identify the entities of interest in any such problem, describe each entity in terms of the special concepts specified by the knowledge base, testing the resulting solution to assess whether it is correct and optimal; and
3. Control or self-regulation of one's learning behavior: tells instructor they lack comprehension, checks work against instruction for errors or omissions, requests further information if needed, asks divergent and inquisitive questions, or offers insightful and alternate explanations.

The rational supporting the above mentioned exclusions stems from a belief that teaching students (a) sets of learning strategies, (b) heuristic for solving problems, or (c) recommending self-regulating behaviors that have the potential to lead to success on a given task. However desirable these competencies may be, the competencies, per se, do not guarantee an awareness of one's thoughts, nor the ability to contemplate the rational arguments used to support one's knowledge claims. What is involved in these competencies is the observable feature of successful or desirable performance. Successful or desirable performance merely entails a reflection on *selecting* correct strategies (i.e., knowing what to choose in terms of solution attainment and efficiency). This does not mean, however, that I am of the opinion that learning strategies or self-regulating tasks cannot occur within the metacognitive realm. To do so, however, is a more complex task involving knowledge or awareness by the learner that these are appropriate strategies to apply in order to execute the task successfully. This task entails, not just selection of the correct strategies to employ, but a *reflection* on other potential or competing strategies to know why they do not work, or why they are effective, or if selected, what errors or positive effects may result. The distinction is analogous to that posed by Kuhn *et al.* (1989): the ability to think *about* the significance of a specific strategy as opposed to merely unreflected execution of a set of strategies.

In summary, I consider a learner who displays evidence of metacognitive ability as standing in direct contrast to an individual who merely uses his or her conceptions as a means of organizing experiences and thinking about the world. An individual who uses his or her conceptions to think *with* may not necessarily think about the conceptions themselves or contemplate the rational arguments used to support his or her knowledge claims.

Educational Goals and Research Based Teaching-Learning Strategies Employed During Project META

The general educational goals employed during Project META were to make public the learner's existing conceptions, yet at the same time help him or her to alter fundamentally their non-canonical conceptions about the science phenomena under consideration. Thus, creating a learning environment in which the learners' current conceptions, the status of their conceptions and the reasoning used to support their constructs was the central foci of instruction during Project META.

It is important to keep in mind that the specific researched based teaching-learning strategies listed below were not tied to any specific science unit nor were they an end in themselves. Rather, they were considered a means to facilitate the creation of an intellectual environment, free from dogmatic evaluation, in which students were encouraged to make public: (a) their epistemological beliefs about how knowledge should be developed, and (b) their metaphysical beliefs about the nature of the world. The strategies are divided into four major categories illuminating the role of the teacher, the learner, the instructional activities, and the instructional assessment.

Role of the Teacher. Taken collectively, all the teaching strategies employed during Project META have been thoroughly discussing in the literature. They were to:

1. Focus on ways of making public learners' ideas/beliefs, that is, finding ways in which learners can externally represent[2] their ideas/beliefs about the topic under consideration (Hewson & Thorley, 1989; Thorley, 1990);

2. Make provisions for learners to be able to clarify their ideas/beliefs through small group work (Children's Learning in Science Project, University of Leeds--Great Britain; the Project to Enhance Effective Learning, Monash University--Australia; and the various projects in teaching for conceptual change at Michigan State University--USA);

3. Encourage/promote metacognitive discourse among the learners in order to illuminate the nature of students' internal representations[3] (White, 1986; Baird, 1986; White & Gunstone, 1989; Hewson & Thorley, 1989; Thorley, 1990; Baird, Fensham, Gunstone, & White, 1991; Gunstone, 1992; Hennessey 1991, 1991b, 1993; Hennessey & Beeth, 1993, Beeth, 1993b);

4. Use learners' external representations as a way of evaluating their ideas/beliefs (in terms of intelligibility, plausibility, and fruitfulness) in order to facilitate/promote conceptual capture or conceptual exchange within the minds of the learner (Hewson & Thorley, 1989; Thorley, 1990; Hennessey, 1991b),

5. Ensure that there will be direct contrast between learner's views and the desired canonical view (Hewson & Hewson, 1988), either by presenting experiences that are inconsistent with students' initial conceptions (Minstrell, 1985), or by engaging in "ideational confrontation" (Champagne, Gunstone, and Klopfer, 1985), "conceptual conflict" triggered by a "discrepant event" (Roth, Anderson, & Smith, 1987);

6. Employ "bridging analogies" from "anchors" in dealing with students conceptions in physics (Clement, Brown, & Zietsman, 1989; Brown, 1992; Brown & Clement, 1992; Clement, 1993);

7. Provide immediate opportunities for learners to apply their newly acquired understanding to different examples (Hewson & Hewson, 1988) or phenomena of their own interest so that they can develop complex problem-posing and problem-solving skills (Stewart, 1983; Jungck & Calley, 1985; Thompson & Stewart, 1985, Stewart, 1988);

8. Provide time to discuss the nature of learning, the nature of science, and the historical precedents of scientific theory building, and the plurality of languages for describing reality (Carey, *et al.*, 1989; Lederman, 1992; Roth & Roychoudhury, 1994).

Role of the Learner. Several learning goals were operating during Project META. The primary purpose of each goal was to give direction to the students as to how they could best take control over their own learning situation. Not all the learning goals were simultaneously presented; but, over a six-year period they were explicitly posed to each cohort of students. The learning goals were to:

1. Be able to state explicitly their own views (ideas/beliefs) about the topic under consideration;

2. Consider the reasoning used to support their views;

3. Look for some consistency among their views;

4. Explore the implications of their views over a wide range of activities while looking for underlying commonalties;

5. Consider the implications and limitations of the view they currently held or were currently considering and the need for possible revision;

6. Explore abstract concepts, propositions, or theories by constructing physical representations of their current views or by employing analogies, metaphors, real world prototypical exemplars or conceptual models;

7. Distinguish on a minimal level the difference between the terms intelligible, plausible, and fruitful (grades 4, 5, 6) or to distinguish the difference between understanding an idea and accepting that idea to be "true" (grades 1, 2, 3);

8. Explicitly talk about the status of the conceptions they held or were currently considering (grades 4, 5, 6)

9. Explicitly refer to their own thinking or learning process.

Role of Activities or Tasks. Hands-on, inquiry-based science instruction[4] was an integral component of each science unit. The instruction activities were designed to engage students in (a) reasoning that required them to think about and apply their ideas to both familiar and new situations, (b) to look for consistency and generalizability in constructing new knowledge and (c) to help students see the interconnections among scientific ideas. Each learning task or activity employed during Project META had the potential to:

1. Actively engage the learners in considering their own ideas/beliefs;

2. Encourage the learner to consider the reasoning used to support his or her own ideas/beliefs;

3. Engage/promote metacognitive discourse among the learners,

4. When necessary, create conceptual conflict or dissatisfaction with the learners' current ideas/beliefs by (a) being discrepant to the learners' ideas, or (b) serving as "bridge" between students intuitive ideas and the canonical explanations;

5. Make public the status of the learners' conceptions: that is, the implementation of both status-lowering activities (activities that allowed for a direct contrast among student views in order to show that some explanations/views are more viable than others) and status-raising activities (activities in which conceptions expressed from a canonical view point were employed to explain common events or applied to new situations); and

6. Remove the classroom teacher as the ultimate authority figure.

Role of Assessment. Assessment was on going and closely linked to instruction. Students were offered many different options for communicating what they knew and understood, and for raising new questions about the topic under consideration. These options included demonstrating ideas, quantify results, making written, oral or visual presentations of findings, conclusions, or ideas. The assessment utilized during Project META required thought beyond mere recognition and recall. Its goals were to:

1. Help students explicitly reflect on their own learning by encouraging learners to apply, in a manner meaningful to them, their conceptual understanding of the topic under consideration to a new or related phenomena in order to explain or make predictions about the phenomena in question;

2. Encourage students to draw upon the knowledge they already possessed and to apply their understanding to create new ideas, enhance human relations, expand awareness of their natural world, or enrich their own experiences, and

3. Develop their communication processes (listening, speaking, writing, viewing, image making, and other symbolizing) to enable them to communicate their thoughts to others.

In summary, integrating the roles of teacher, student, instructional activities, and instructional assessment to (a) create a teaching-learning environment that valued student thinking and (b) to support learning science content at a conceptual level was the responsibility of both teacher and students. Finding ways to integrate successfully my views of what it means to know, understand, and learn with my students' views of what it means to know, understand, and learn without imposing my meanings on the students served as the core of the instructional design of Project META.

Data Collection

The data for this study was gathered over a three consecutive academic years, in a naturalistic classroom setting, as students worked through their everyday science classes. During that time, each of the six cohorts of students worked on at least three different units in physical science (In order to control the volume of data collected and analyzed, this study was limited to probing the students' concepts of physical science content.) The physical science content included units on: force and motion (grades 6 & 5); heat and temperature (grades 6 & 4); nature of gravity (grades 6 & 3); particulate nature of matter (grades 5 & 4); chemical /biochemical reactions (grade 5); pressure & buoyancy (grade 4 & 3); electricity & magnetism (grade 3 & 2); matter in solution (grade 2); light & color (grade 2 & 1); mirrors & lenses (grade 1); and sinking and floating (grade 1). In addition to the science content, several units probed students' conceptions of the nature of science, the nature of knowledge production and learning, and the nature of explanatory models in science.

As small-groups of students represented their thinking or revised their models, they audio recorded their conversations using unidirectional microphone attached to portable cassette recorder. Likewise, all whole-group classroom discussions were either audio or video recorded. A subset of the student generated audio recordings and all of the whole-class generated audio/video recordings were later transcribed and comprise most of the data used in this study.

In addition to the audio/video recordings, data from two other sources were included. First, written materials produced by the students were collected and analyzed for metaconceptual content. To encourage the students to write as they worked, each group of students had access to a computer and word-processor in which the students were instructed to record any notes or ideas they considered important. These electronic-notebooks were introduced midway through first grade and were an integral part of classroom practice for all student to matriculation at the end of sixth grade. Second, representations of studentsí conceptions in the form of illustrations on posters or constructed conceptual models were also included in the analysis. It is important to keep in mind that the procedures used to gather data during Project META were not initiated solely for this study. Thus, representing and communicating conceptions in terms of illustrations on posters or conceptual models, audio/video recording small group and whole group discussions to communicate and capture representations of intuitive theories and familiarity with word processing were an integral and normal part of established classroom practices.

Data Analysis

Data analysis for this study was conducted in three stages.

Phase One: Structure of Analysis Scheme

In the first phase of the analysis, six categories were developed to characterize the facets of higher-level metacognitive thought produced by the students as they represented or revised representations of their thinking about the content in question. The first five categories are descriptive in nature and were derived from preliminary analysis of transcripts. The sixth category was included to probe components of individual student's conceptual ecology.[5] The six categories are described below.

1. *Conceptions* . This category includes any metacognitive statements in which the student is engaged in considering his or her conceptions of the content in question.

2. *Reasoning* . This category includes any metacognitive statements in which the student refers to the reasoning used to support his or her conceptions.

3. *Implications* . This category includes any metacognitive statements in which the student is explicitly considering the implications or limitations inherent in his or her conceptions.

4. *Thinking Process* . This category includes any metacognitive statements in which the student is explicitly considering his or her thinking or learning process as an object of cognition.

5. *Status* . This category includes any metacognitive statements in which the student is commenting on the status of conceptions (i.e., explicitly commenting on the intelligibility, plausibility, and fruitfulness of the conception under consideration).

6. *Conceptual Ecology* . This category includes any metacognitive statements in which the student refers to or specifically uses any components of his or her conceptual ecology.

Once the categories were identified, further analysis proceeded through the steps described below.

Issues: Phase-One Analysis Scheme. Three issues in connection with the analysis scheme are important. First, the categories are not independent of one another, since they represent multi-faceted components of the students' conceptions. I therefore expect that important relationships exist between them. For example, an individual cannot consider the implications of his or her knowledge claims (facet 5) or the reasoning used to support knowledge claims (facet 4) without first considering the content of his or her knowledge claims (facet 1). Second, the sixth category, components of conceptual ecology, has been added to explore the possibility of identifying characteristics of each component of the conceptual ecology. This category is considered to be both descriptive and interpretive in nature. Explicit and reliable references to each component of the conceptual ecology would provide an optimal data set. Some components, such as use of analogies, metaphors, exemplars, and images, were expected to be relatively easy to identify in the discourse. Other components, however, such as epistemological commitments, metaphysical beliefs, and recognition or reconciliation of anomalies were not expected to be explicitly articulated by the learners. Thus, the discourse assigned to this category required further analysis and interpretation on my part. Third, the descriptive categories are broad. The decision to work with broad categories was prompted by two considerations. First, the task of categorizing statements into broad categories was significantly easier to accomplish. It was not obvious, at this stage of analysis, that a more in depth analysis was necessary in order to characterize the different facets of students' metacognitive discourse. Second, it was not clear that it was possible to define each category with the degree of precision required to allow statements to unequivocally categorized.

Use of Analysis Scheme: Phase-One. In order to know more about the nature of metacognition, and to characterize facets of higher-level thought (Aim 1), analysis proceeded through the following steps:

Step I: The analyst read the transcripts, identified each segments cognitive level, that is, whether it was metacognitive or not. Any statement produced by either the students or me that were not metacognitive in nature and any metacognitive statements produced by me were excluded from further analysis.

Step II: The analyst coded the remaining discourse segment in terms of the first five analysis categories. Each statement was then placed within its appropriate category. If the segment applied to more than one category it was placed both. As mentioned above, the multi-faceted nature of the discourse facilitates overlapping boundaries. This stage is exemplified in the discussion of data section below.

Step III: The analyst appended annotated comments to large segments of discourse. The comments included remarks (where appropriate) about the student's: (a) prepositional knowledge or belief claims about the science content under investigation; (b) metaphysical beliefs about what is considered to be true about the real world or qualities of objects; (c) epistemological commitments (e.g., consistency in reasoning and generalizability of that reasoning to other circumstances); and (d) explicit use of analogies, metaphors, real world prototypical exemplars or conceptual models. Examples of this are exemplified discussion section.

Step IV: The analyst adapted the analysis scheme of Step III to include a more detailed analysis of each segment (sentence by sentence) of metacognitive discourse. Its purpose was to determine whether characteristics of each component of a learner's conceptual ecology could be identified. This more demanding extension of the analysis was used on a limited base. Discourse analyzed using this extended procedure which illustrated components of the learner's conceptual ecology was assigned to category six.

Phase Two: Structure of Analysis Scheme

In order to know more about the process by which individuals change their metacognitive capabilities (Aim 2) a second analysis scheme was developed which consists of a *comparison between conceptions.* It was hypothesized that similarities and differences between selected components of an individual's conceptions could be considered and compared with the same components of the individual's conceptions over multiple years. This entailed a systematic analysis of available classroom discourse to identify recurring themes that could be utilized as a database to (a) select individual students for the comparison; and (b) to determine which components of the selected students' conceptions could be compared across a three year period. Operationally, a recurring theme is identified as a topic that recurs in the classroom discourse (at any grade level) for three consecutive years. The form of analysis consists of five recurring themes derived from the discourse, which are described below.

1. Knowledge Theme: This category includes any metacognitive statements in which the student is engaged in considering his or her conceptions about how knowledge is produced.

2. Learning Theme: This category includes any metacognitive statements in which the student is engaged in considering his or her conceptions about learning in general or specific strategies that (from the student's perspective) will lead to further learning.

3. Ideas Theme: This category includes any metacognitive statements in which the learner seeks to articulate his or her understanding about the term idea.

4. Science Theme: This category includes any metacognitive statements in which the learner seeks to articulate his or her understanding about the nature of science in general or the nature of "school" science in particular.

5. Conceptual Model Theme: This category includes any metacognitive statements in which the learner explicitly refers the nature or use of conceptual models in science.

Once the recurring themes were identified, an analysis matrix was created whose columns were formed by multiple academic years and whose rows were formed by the five main themes categories identified above. To carry out the analysis, the analyst placed focus statements (from Step II below) in the appropriate cells of the matrix, looked for patterns in the matrix to identify any student who may have commented on the identified themes over three consecutive academic years. Further analysis proceeded through Steps V and VI described below.

Issues: Phase Two analysis Scheme. Three issues in connection with the analysis scheme are important. First, the themes that emerged as result of this phase of analysis was specifically tied to curriculum and instruction issues. For example, most science units were not repeated on a yearly cycle (i.e., if a class studied a unit on heat and temperature in fourth grade, the topic of heat and temperature was not formally addressed in *both* fifth and sixth grade). Therefore, over the course of a three-year period, the individual did not have an opportunity to extensively comment on his or her conceptions of a specific science concept. Thus, it was expected that students' conceptions of specific science content would, necessarily, be excluded from this analysis scheme. Second, the available data source for the comparison of conceptions analysis was further reduced because not all students managed to record their thinking on the identified recurring themes across three consecutive years. Finally, the available culled data was frequently from different data sources (e.g., whole class discussions, small-group discussions, or individually word-processed response).

Use of Analysis Scheme: Phase Two. In order to know more about the process by which individuals change their metacognitive capabilities with experience (Aim 2) the analysis proceeded through the following steps:

Step I: The analyst read the transcripts to identify specific themes within the discourse that were repeated over a three-year period. Five recurring themes emerged and were used as classification categories across a three-year time frame.

Step II: The analyst coded discourse segments in terms of the five recurring themes and wrote short statements summarizing the focus of each discourse passage.

Step III: The analyst entered all individual focus statements in an analysis matrix. If a statement applied to more that one theme category or more than one academic year it was placed in both. This step is exemplified in Figure 1.

Step IV: The analyst inspected the completed matrixes to identify any students who commented on a specific theme or themes across all three academic years. Once identified, the student's comments were considered for further analysis.

Step V: The analyst appended annotated comments to the identified theme or themes following the same procedures as Steps III and IV of Phase One.

Step VI: The analyst carried out a comparison between conceptions, identifying similarities and or differences that exist in the individual's representation of his or her conceptions during Year I, Year II, and Year III of the study respectively. This step is exemplified in Figure 2.

An example of Phase II analysis is provided in the discussion section below.

Figure 1 About Here

Phase Three: Structure of Analysis Scheme

To date there is no consensus within the research community about ways in which metacognition can best be promoted nor is there a consensus as to the role metacognition plays in facilitating conceptual understanding. To know more about the relationship among pedagogical practice, metacognition, and conceptual understanding (Aim 3) a third analysis scheme was devised. It was hypothesized that pedagogical practices in general are linked to changes in metacognitive ability. Likewise, it was hypothesized that metacognitive ability is linked to changes in conceptual understanding. What is lacking, to date, is a description of the nature of these links. In order to frame this phase of the analysis it was necessary to find a way that I could get a sense of (at least partially) the nature of the links among pedagogical practice, metacognitive ability, and conceptual understanding respectively.

Phase-One data analysis scheme provides insights into the kind of higher-level metacognitive thinking and reasoning that seems necessary for learners' to be able to consider their conceptions as objects of cognition so that they can evaluate their own understanding and personal constructs. Phase-Two data analysis scheme provides insights into the ways in which metacognition can change with experience and provides a link between changes in metacognitive thought and concurrent changes in conceptual understanding. It seems intuitive to claim that the specific pedagogical practices at work in the educational environment are, at a minimum, supportive of the observed changes in metacognition. Likewise, it seems intuitive to claim the same supportive relationship exists between metacognitive ability and conceptual understanding.

The purpose of Phase-Three data analysis scheme was to gather some evidence to substantiate the above intuitive claims. The collaborative construction of meaning (a pedagogical practice whereby students construct common shared meanings by a process of consensus) was selected to contextualize the analysis. This selection was made for several reasons. First, the data contained many instances of students collaboratively negotiating meaning for specific terms and concepts; thus, the analysis could proceed readily. Second, selection was based on belief that metacognition coupled with the collaborative construction of meaning are intertwined and are supportive of subsequent conceptual change. Third, the process of collaborative construction of meaning and conceptual understanding could be followed simultaneous.

Since the notion of status is central to the process of conceptual understanding (Posner *et al.* , 1982; Hewson, 1981, 1982) I thought it would be interesting to analyze the students attempt to negotiate meaning for the term intelligible. The analysis consisted of several steps and is described fully below.

Issues: Phase Three Analysis Scheme. Phase-analysis raises interesting questions about the relationship among: (a) pedagogical practice (the roles of the teacher, student, activities, and assessment that guided this study); (b) students' conceptions of science content and its susceptibility to change; and (c) the role of higher-levels metacognition play in effecting changes in students' conceptions. These issues are of prime interest, however, they will not be considered in during this phase of analysis. Rather, the intent is to demonstrate that: (a) the collaborative construction of meaning can successfully be negotiated among young children; (b) the negotiations, at time, include sophisticate levels of metacognition; and (c) the levels of metacognition are a mechanism of support for conceptual understanding.

Use of Analysis Scheme: Phase Three. To know more about the nature of the relationships among (a) the pedagogical practice in place within the science classroom, (b) the studentsí metacognitive ability, and (c) the studentsí conceptual understanding the analysis proceeded through the following steps:

> *Step I:* The analyst read the collection of posters and word processed responses (produced at the beginning, mid-way through, and at the end of the negotiation sessions), identified initial and final understanding of the term intelligible, and determined whether individual student's understanding about the term intelligible had changed. The step is exemplified in Table 1.
>
> *Step II:* The analyst read the transcripts, identified length segments of discourse pertaining to collaborate negotiation of meaning for the term intelligible.
>
> *Step III:* The analyst appended annotated comments to the identified instances of collaborative negotiations following the same procedures as Stages III and IV of Phase One.
>
> *Step IV:* The analyst prepared an interpretive chart of students' classroom discourse, looked for patterns of linkage between changes in conceptual strategies (inferred from practice) and changes in facets of metacognitive thought. This step is exemplified in Table 2.

An example of Phase III analysis is provided in the discussion section.

Results of Data Analysis

The central focus of this paper is to describe a class of higher-level knowledge associated with the process of metacognition displayed by elementary school children (ages 6-12). This entails a systematic analysis of classroom discourse rich in metacognitive statements. Several characteristics of the analytic process are worth discussion further. These characteristics are illustrated below with results of analysis.

Aim I: Facets of Metacognitive Thought

In an effort to both explicitly promote metacognition within the science classroom and to conduct research on the nature of students' metacognitive reflections, I have noticed a significant difference in the type of metacognitive reflections produced by students. Thus, the first goal of this study sought to characterize the nature of these differences. A framework, in the form of a system of categories was established to analyze students' metacognitive statements. The categories are not necessarily hierarchical in nature, although they do reflect an increase in metacognitive sophistication on the part of the students.

Data analysis clearly supports the view that the students in this study provide extensive and varied evidence of their metacognitive capabilities. The data also supports the claim that there is a qualitative difference among the metacognitive statements produced by the students in this study. The differences in metacognitive ability range from a minimal level of awareness of one's conceptions to various levels of more sophisticated metacognitive thought. In order to clarify the nature of these qualitative differences in metacognitive thought, examples of student's discourse that are reflective of the six analytical categories (Phase-One Analysis Scheme) are provided. The examples presented here form a small part of the complete study in which approximately 140 students participated (each academic year). In addition, the examples of students' metacognitive discourse presented in this paper are highly representative of well over half of the students in richness of metacognitive statements. Lastly, discourse segments contain examples of both canonical as well as non-canonical views of science. Other details, specific to each task, are outlined as they occur.

Conceptions Category: Reflections That Explicitly Refer to Personal Constructs or Knowledge Claims

Included in this category are metacognitive statements in which a student explicitly refers to his or her own conception. Evidence of the individual's ability to explicitly think <u>about</u> the ideas or conceptions he or she holds or is currently considering is a minimal requirement for the discourse to be assigned to this category. Explicit reference to a peer's, teacher's, or the scientific communities' representation of a conception is a simple extension of the above requirement and is likewise assigned to this category.

<u>Example 1: Context.</u> The following is an extract from a transcript of a grade five small-group discussion. The focus of the discussion centers on the book on the table task in which the students are asked to give an explanation of the force or forces acting on the book as it rests on the table.

> Dani: I think there is only one force acting on the book on the table. The one force comes from gravity. There is an interaction between the book and the table but I don't think this interaction is a force like gravity. It is more of a blocking force. (Project META, grade 5, Year 2--1992-1993)

<u>Annotated comments.</u> Dani's comments provided evidence that she is capable of describing her ideas about the force acting on a book as it rests on a table. In doing so, she provided valuable information about her personal belief about the "interaction" between the book and the table: "it is more of a blocking force."

<u>Example 2: Context.</u> The following is an extract from a transcript of a grade six small-group discussion and is illustrative of a student who explicitly refers to a peer's conception. The discussion focuses on the possibility of objects moving, when the forces acting on it are balanced.

> Katie: [Speaking directly to a classmate] I know what you are saying hum (pause) you think that balanced forces are a good explanation for things at rest and that's ok but what about things moving at a steady pace? They have balanced forces too, (pause) don't they? (pause) Like I don't get how you could have the same explanation for two different things" (Project META, grade 6, year 1--1991-1992).

<u>Annotated comments.</u> It appears that Katie is aware of her peer's thinking ("I know what you are saying...you think that..."). She concurs with her peer's idea that "balanced forces" are a good explanation of objects at rest by revealing her opinion ("...and that's ok"). She spontaneously asks her peer about objects moving at a steady pace (constant velocity) and reveals her thoughts about the type of forces acting on objects exhibiting constant velocity ("...what about things moving at steady pace?...They have balanced forces too, don't they?"). Katie's confusion about how her peer "could have the same explanation for two different things" reveals major shortcomings in her understanding of Newtonian physics, namely that both constant velocity and at rest have the same force explanation. For Katie, the possibility of an object moving, even if the forces acting on it are balanced is an idea that she is willing to question.

Both Dani's and Katie's comments are representative of the types of statements placed in this category.

Reasoning Category: Reflections That Explicitly Refer to the Reasoning Used to Support Personal Constructs or Knowledge Claims.

The ability to examine *why* one is attracted to specific knowledge claims, ideas, or concepts goes beyond the recognition of one's own prepositional knowledge claims. Metacognitive statements that explicitly refer to the reasoning used to support a learner's constructs are included in this category.

Context. Chad, a grade three student, word-processed his response to the following set of questions. "In your opinion, what do you think science is all about? What is science for you? Why do think this?

> Chad: I think science is thinking about your thoughts. You have to use your ideas if you want to think about things like how gravity works, how the seasons change etc (sic). I don't think you can do science like experiments without thinking about your thoughts because you need your thoughts and ideas to figure things out. I also think science is questioning other people and thinking about their thought too. And I think science is trying out your ideas to get a better idea, and telling other people about your ideas.
>
> Science is also technology like this computer and the TV sets and the microscopes. People has (sic) to use there (sic) thoughts and ideas to make technology happen.
>
> I am not to sure why I think this about science because I have a lot of ideas in my head and I am not sure what ones are the best. I think all of those ideas about science because this was the best idea I could think of for now. But maybe someday I will think something different. I don't have a good reason why I think science is about understanding ideas I just do (Project META, grade 3, year three--1993/94).

Annotated comments. Chad's comments provide evidence that he is capable of describing his personal constructs about the nature of science. Chad readily acknowledges he is unsure of the reasoning he is using to support his constructs (...I am not sure why I think this about science...I don't have any good reason why I think science is about understanding ideas I just do.) Chad's attempt to examine the reasoning he uses to support his claims is representative of the type of statements assigned to this category. More than three-quarters of the statements assigned to this category contain evidence that the students in question can articulate clearly the reasoning underlying their claims.

Implications Category: Reflections That Explicitly Consider the Implications or Limitations Inherent in Personal Constructs or Knowledge Claims.

Included is this category are metacognitive statements which are indicative of a learner's ability to explicitly consider the potential strengths or weaknesses of his or her conceptions, or provides evidence that the learner is aware of the possible limitations of his or her conceptions. The ability to explicitly consider one's conceptions as having the potential to be effective or ineffective (i.e., to consider what errors or positive effects may result when specific concepts are applied to a new or similar situation) is indicative of a high-level of metacognitive thought processes.

Context. The following is an extract from a transcript of a grade six small-group discussion. The discussion focuses on the individual student's beliefs about molecular motion.

> Luke: I have no problem understanding the ideas behind water changing from a solid to a liquid to a gas. Like when ice melts the molecules in ice move faster and break away from each other and when the water changes to steam the molecules are moving even faster. That's easy to say and I can tell you about it. It's just (pause) just (pause) I don't know if I really believe all that. It's the constant motion of molecules in solids that bothers me. <t: In what way?> (Pause) Well not liquids and gases (pause) I mean like experiences help me to believe in molecules in motion. <t: I'm not too sure if I understand what you are saying. Can you give examples?> (Pause) Yeah, like the air in this room, hum it moves out of my way so I can move through it easily and (Pause) water in a swimming pool I can dive through it. But I don't have any real experiences with moving molecules in solids. <t: Why? What's different about solids?> Like this stool or this station the molecules are suppose to be in constant motion. But I really don't know that for sure I guess I just have to believe it. But the worse part is if I choose not to believe in the molecules moving in this stool then my whole theory of heat doesn't work and I don't want to give up my theory of heat because I think it is a good explanation (Hennessey, 1991).

Annotated comments. Luke provides evidence of his ability to articulate his personal beliefs about molecular motion and draws on his past experiences as evidence to support his beliefs. Luke also provides further evidence that he is aware of a view of molecular motion that is in direct competition to his own ("...the molecules are suppose to be in constant motion..."). He explicitly considers the weakness in his present view ("...I don't know if I really believe all that. It's the constant motion of molecules in solids that bothers me...I really don't know for sure I guess I just have to believe it..."), and articulates the problem inherent in not changing his current view ("...If I choose not to believe...my whole theory of heat doesn't work..."). Luke's statement is representative of the type of comments assigned to this category.

Thinking Process Category: Reflections That Explicitly Refer to Personal Thinking or Learning Process.

Included in this category are metacognitive statements that clearly indicate the students' ability to reflect on their thinking/learning processes as objects of cognition.

Context. The following is an extract from a transcript of a grade four whole-class discussion. The students are asked to explain how they determined the plausibility of an idea. I opened the discussion with the following remarks:

> Teacher: ...I guess, in one sense, what I'm really trying to get at is: How do you determine what science content to believe? It's a fact that you have made decisions all year long. Decisions on whether to accept or reject a stated idea. Some how some way, you based whether you want to believe an idea, or lesson, or content on some factor. In other words, when you hear an idea for the first time what do you do with your own thoughts? How do you decide whether to accept, or reject an idea? Now, does anyone want to try to put his or her thoughts into words? Ok...

[During the course of three class periods, fifteen out of 18 students responded to the above probe. The following extracts is representative of the quality of responses given by the students who responded to the probe.]

> Eamon: ...I try to look for a fit. Like if it doesn't fit with any of my (pause) all [with emphasis] of my ideas that I have in my head I just leave it and wait for other ideas to come in so that I can try to fit them together with my ideas. Maybe they will go with my ideas and then another idea will come in and I can fit it together with that idea and my understanding just keeps on enlarging. An idea usually does finally fit.
>
> Teacher: Eamon, what do you mean when you say you wait for an idea to come in? Do you think ideas come into your head?
>
> Eamon: It's just an analogy. Like Kelly's throw it away analogy. I don't think Kelly really means you can throw ideas away <Kelly: Right> and I really don't think ideas can (pause) can like jump out of someone's head and into mine. I mean (pause) people talk and I hear what they say. You talk and I hear what you say. But I have to decide what to do with what you say (pause). I have to see where it fits in with the ideas in my head. But sometimes I can't connect it. <t: Why?> Because I don't have enough pieces yet (pause) so I just hang on to the idea. Or sometimes what I hear isn't plausible to me then I don't try to connect it.
>
> Teacher: Are you saying that if you hang on to an idea long enough you can usually see how it relates to your own ideas? That some how, some way, you can usually find a way to make a connection?
>
> Eamon: Yeah. But the idea has to make sense or I don't even try to connect it. I won't try to connect unsensible ideas. I mean like if the idea isn't plausible why connect it.
>
> Teacher: Do you think that perhaps an idea that isn't plausible to you now can change to a plausible idea later?
>
> Eamon: No (pause). Well yes I guess. But it isn't going to change to plausible all by itself. I have to get more pieces (pause) I mean (pause) well (pause) hum. No wait. (Laugh) It's hard to say it in words. <t: I know.> I have to (pause) make the not plausible idea plausible and some ideas I won't even try to make plausible because they just don't make any real sense like curtains eat ice cream. I won't try to make that idea plausible because I know for certain that curtains are not living and do not eat. But an idea like: nothing between the spaces of molecules is different. I would keep trying to get more pieces to turn this to plausible. But I can't turn it to plausible until I have enough pieces (pause) I just keep this idea until later (Project META, grade 4, year 1--1991/92).

Annotated comments. In this excerpt Eamon demonstrates very impressive metaconceptual ability by articulating his own thinking about his thinking-learning processes. ("...I look for a fit...If it [the idea being considered] doesn't fit I just leave it and wait for other ideas to come in so that I can try to fit them together with my ideas..."). He refers to his policy of trying to "fit ideas together." When questioned about the meaning he attached to the phrase "wait for an ideas to come in" Eamon is quick to respond that he is using the phrase as an analogy. He explain this by referring to Kelly's comments ("...it's just an analogy...like Kelly's...I don't think Kelly really means you can throw ideas away..."). A key components of Eamon's thinking process is his understanding of the importance of trying to make a connection between what he already knows (his current conceptions) and idea under discussion ("...I have to see where it fits with the ideas in my head...sometimes I can't connect it...because I don't have enough pieces yet so I just hang on to the ideas...sometimes what I hear isn't plausible to me then I don't try to connect it...I mean like if the idea isn't plausible why connect it..."). When I probed his thinking about the possibility of changing an idea that is not plausible to him to an idea that is plausible, Eamon explains how he thinks this process could occur. He indicates that changes in plausibility do not take place automatically; ("...It isn't going to change to plausible all by itself. I have to get more pieces...its hard to say in words [explain]...I have to make the not plausible idea plausible and some ideas I won't even try to make plausible because they just don't make any real sense..."). Statements assigned to this category (when considered individually) provide further evidence to support the claim that when given the opportunity, students can and do display highly sophisticated metacognitive capabilities that go far beyond prepositional statements of understanding or belief.

Status Category: Reflections That Explicitly Refer to the Status of Personal Constructs.

Included in this level are metacognitive statements that demonstrate the ability to explicitly comment on the status of one's conceptions. Evidence of status is reflected in a person's ability to: (a) explicitly reflect on his or her conceptions as objects of cognition; (b) temporarily bracket and set aside his or her knowledge or beliefs in order to talk about the intelligibility, plausibility, and fruitfulness of that conception, and (c) provide some evidence of his or her understanding of the individual terms (intelligible, plausible, and fruitful) of the conceptual change model.

Context. The following extract is from a transcript of a grade four whole-class discussion. Prior to the discussion the students were shown a series of overhead visuals that depict a canonical explanation of the arrangement and motion of atoms during phase changes, (i.e., a molecular explanation of the difference between a solid, liquid, and gas). The students were free to comment on the visuals in a manner considered meaningful to them. In other words, the status comments were unsolicited and occurred spontaneously. I prefaced the class discussion with the following remarks:

> Teacher: ...for now we had better return to our original task. [referring to the visuals on the marker board] Ok. Let's get back to these drawing on the board. I'd like you to keep in mind that as you start taking a look at other peoples' ideas, that is, ideas that are not our own, you may find yourself asking yourself: Do I accept that explanation or not? Do I accept their explanation for what is going on? You're probably sitting here saying: Well, if it goes with my theory of how things work, I do. Or as Kelly said: if it goes with my experiences, I do. But as Pat said, you don't have experiences with atoms. However, I know you all have ideas about atoms. Hum you have some mental picture in you mind about what an atom is or what a molecule is. You've even draw up you ideas for me a few times and I've even seen you changed your drawings a few times because your ideas about atoms have changed. (Pause) Hum perhaps you will even change your ideas some more. So the question is: Do the ideas of other people fit with your ideas? If they don't fit with your theory then what? Well perhaps, like Kelly, you may say I'm going to set them asides for a while because after all these are physicists ideas. I guess they know what they are talking about but they don't go with my ideas just yet. So you leave them out there. And it's ok to do that. Why? Because there is no use repeating back to me something you don't believe in just for the sake of a grade because your grades aren't based on your ability to repeat other people's idea back to me. So it's ok to let them sit out there. Or perhaps, like Eamon said, later on when I get some more bits and pieces I can reach out and bring the physicists ideas in to my own ideas because they fit with the way I think or because they help me think of things in a different way. Ok. That enough, I'd better stop talking. What I would like you to do is to go back into your small groups and to spend some time talking about the visuals in your small groups. What does the individual visual mean to you? Go ahead. I'll call you back later to share your ideas with the whole group. [Students return to large group setting] Ok. Who wants to begin the discussion? What do the visuals [cut off]...

[During two class periods thirteen of the eighteen students responded to the probe.]

Teach: Ok. Kathryn. Go ahead.

> Kathryn: First I think that all of the pictures are I, P, and F for me 'cause they are useful to my ideas. I was trying to put my ideas together something like that [points to visuals] but I didn't really have (pause) such a good picture. Hum. Like those pictures are better than I drew my pictures but I think the ideas are the same as my ideas. I understand all of them and I believe all of them and I think all of them are useful to my ideas because they have help (pause) help me (pause) shape up my ideas. They didn't change my ideas but they did help me (pause) make my ideas clear so that I could tell them better tell them to the group. I mean hum (pause) I knew what I was thinking but I was having a hard time explaining my thinking (pause) and those pictures helped me explain my thinking better.
>
> Teacher: Ok. I think I hear you saying, I had this mental picture of atoms but when I tried to represent my mental picture to others I couldn't really do it as well as these pictures.
>
> Kathryn: Yeah. It was sorta like what David and Eamon said I had all these bits and pieces of ideas but when I saw those pictures they helped me put those bits and pieces together. And because those picture help me put the pieces together I can better explain my ideas about the molecules and how they vibrate and move away from each other as they change from solids and liquids and gases to the group. So I think the pictures are fruitful for me (Project META, grade 4, year 1--1991-91)

Annotated comments At first Kathryn states the visuals are " I, P, and F" [intelligible, plausible, and fruitful] without providing any further explanation as to what the terms meant to her. She then compares the concepts represented by the visuals to her own attempt to represent her thinking. She is aware that the visuals are more sophisticated but remarks that the content of the visuals represent ideas that are similar to hers ("...those pictures are better than [the ones] I drew...but I think the ideas are the same as my ideas.') Later, Kathryn provides direct evidence that she understands the meaning of the terms intelligible, plausible, and fruitful ("...I understand all of them [the three visuals] and I believe all of them and I think all of them are useful to my ideas..."). In addition, she provides indirect evidence that she understands the meaning of the visuals ("...molecules...vibrate and move away from each other as they change from solids and liquids and gases..). For plausible, the evidence is ambiguous: (the ideas are the same as my ideas...they didn't change my ideas but they did help me [to] shape up my ideas...make my ideas clearer so that I could tell them better to the group..."). For fruitful, she provides evidence that the concepts represented by the visuals are, for her, a useful way to describe phase changes in matter ("...they are useful to my ideas...I can better explain me ideas about the molecules...to the group..."). Since Kathryn provides both direct and indirect evidence that she understands the individual the meaning of the terms intelligible, plausible and fruitful, I can trust her determination of status. Kathryn's response is representative of both the solicited and unsolicited status comments assigned to this category. A second example of unsolicited status remarks is given below.

At the beginning of the section on data analysis, I raised the issue of whether it was possible or even useful to define each category with the degree of precision required to allow statements to be unambiguously categorized. The following extract is an example of student discourse, when taken as a whole, could be placed in multiple categories. The student in question begins by providing direct evidence of the status of her conceptions (status category). She immediately shifts the direction of the conversation to refer to the reasoning used to support her status claim (reasoning category). While in the process of clarifying her reasoning, the student reveals her metaphysical beliefs about the nature of atoms (conceptual ecology category) and provides clear evidence that she has considered the implications her beliefs (implications category). The pertinent question is whether or not it is useful to beak up the discourse in to multiple sub-section and assigns each sub-section to its appropriate category or to keep the segment of discourse intact and assign the entire passage to multiple categories. The later course was chosen for this study. The following extract is an example of one student who reveals multiple facets of her metacognitive ability and his highly representative of the comments produced by many of the students in this study.

Context. The following is an extract from a transcript of grade four whole-class discussion. The class discussion is a continuation of the sequence introduced above.

> Melinda: Everybody seems to be talking about whether the pictures were intelligible or not so I'll start with intelligible too. Well their intelligible to me I can understand what the pictures are trying to say about atoms, but they're not plausible to me because I cannot believe from anything that I have done, or anything than I have seen anybody do, that atoms are dead but they can still move. That part is intelligible but not plausible. The pictures are intelligible alright but not the ideas behind the pictures. I cannot understand how molecules can do that [move] if they are dead.
>
> Michelle: That's right Melinda, good job! They are not alive.
>
> Jack: [Interrupting] They're not dead, they're just not alive! <t: laughs>

Melinda: Sure Jack.

Teacher: (Laughing) They're not dead, they're just not alive! I love that! Can you tell me what you mean by that Jack?

Jack: If something is dead that means that at one time it had to be alive. Atoms are not dead because they were never alive. I don't think you can say atoms are dead.

Melinda: Well they are sure not alive.

Jack: I'm not saying they are alive. I'm just saying they are not dead because they did not die. They're just not living and that's not the same thing as saying they are dead.

Melinda: Sure Jack. That sounds the same to me. I don't see what you are trying to say because [interrupt by Jack]

Jack: In my mind what I am saying is clear to me. Dead and not alive are not the same things.

Melinda: But to my mind what you are saying does not make the same sense to me. I know it must make sense to you or you wouldn't be saying what you are saying but it's just not intelligible to me (long pause) I don't see what you are trying to say to me (long pause).

Teacher: Can I jump into this conversation for a minute. That, in one sense you both are saying: we are dealing with the non-living (pause) [writing non-living on board] and that over time I have learned to accept that idea hum that this picture [pointing to visuals] somehow someway communicates motion (pause) [writes motion on the board] a property that Melinda wants to associate with the living. And I think I hear Melinda saying, right now I'm not ready to connect [draws line connecting the terms motion and non-living] the property of motion with non-living. (long pause) Melinda, you're looking at me as if to say: if you put it that way, I'm not too sure.

Melinda: Well it's kinda like, (pause) like hum I don't understand how it could do that. How can atoms move? How [with emphasis] can they do that?

Teacher: So your sitting here saying that, perhaps, I need a how before I can decide whether to accept or reject the idea and without that how you have decided to reject the idea of molecules in motion. <Melinda: yeah.> The idea that molecules or atoms are in motion in just not a plausible idea to you right now. <Melinda: that's right> And that's good because you know where you need to go. You know you need to find [gesticulates quotation marks] how this happens before this idea can become plausible to you. That also tells me: well let's start talking about how. Perhaps not now; but sometime in the near future. Here is a person in front of me who is saying a need a how before I can accept this idea (Project META, grade 4, year 1--1991-92).

<u>Annotated comments.</u> In this case, Melinda states that the conceptions represented in the visuals are intelligible but not plausible to her. She provides direct evidence of her understanding of the technical terms (intelligible, plausible, and fruitful). Therefore I can trust her determination of status ("...I understand what the pictures are trying to say about atoms, but they're not plausible because I cannot believe from anything that I have done, or...seen...that atoms [because they] are dead can still move..."). She continues to reiterate her status claim ("...the pictures are intelligible alright but not the ideas behind the pictures.). For Melinda, her metaphysical beliefs about the nature of atoms [atoms are non-living entities] is clear articulated and appears to be strongly held. She generalizes her misunderstanding about specific characteristic of living things and applies that generalization to non-living objects [only living things have the capacity to move without the influence of an external force]. She likewise provides evidence that she is aware of a contrasting position [atoms are in constant motion] and indicates a lack of understanding inherent in holding that position ("...I cannot understand how molecules [can be in motion] if they are dead..."). At this point in time, Melinda is not ready to equate the property of motion with non-living objects.

In the second case, Jack provides evidence that he understands the nature of Melinda's reasoning and offers an explanation to try and clarify the situation ("...They are not dead, they're just not alive!"). Jack goes on to reveal his own metaphysical beliefs about (1) what it meant to be dead and (2) the properties of atoms ("...If something is dead that means that at one time it had to be alive. Atoms are not dead because they were never alive. I don't think you can say atoms are dead...I'm not saying they are alive...I'm just saying they are not dead because they did not die...and that's not the same thing as saying they are dead"). Melinda, on the other hand, does not grasp Jack's explanation ("...to my mind what you are saying does not make the same sense to me. I know it must make sense to you or you wouldn't be saying what you are saying"). At this point, I interrupt the conversation to clarify the issues being discussed, draw an illustration on the markerboard which represents Melinda's claims, and try to create some dissatisfaction within Melinda's mind. Melinda provides evidence that she understands my illustration, but in order to consider the issues further, she indicates that she needed a mechanistic explanation to further her understanding (i.e., an explanation of <u>how</u> molecules could possible move).

Again, like Kathryn's comments above, Melinda does not provide direct evidence that she able to comment directly about her metaphysical beliefs. It is possible, however, for a researcher to infer that she has revealed certain aspects of her conceptual ecology.

Conceptual Ecology Category: Reflections That Refer to Components of the Conceptual Ecology.

Included in this category are metacognitive statements in which a person: (a) explores his or her metaphysical beliefs about what he or she consider to be true about the real world or qualities of objects; (b) refers to the function of epistemological commitments (i.e., consistency in reasoning and generalizability of that reasoning to other circumstances); or (c) explicitly uses analogies, metaphors, real world prototypical exemplars, or conceptual models. Although it remains to be seen whether students can comment directly on specific components of their conceptual ecologies, it was reasonable to assume that students could provide some indications of their conceptual ecologies. The following two examples, from a first and sixth grades student respectively. The examples are illustrative of Step IV analysis and provide insight into these two students conceptual ecology.

<u>Example 1: Context.</u> The following is an extract from a transcript of a grade one class discussion on floating and sinking. Prior to the recorded discussion, the students spent a full class period exploring the floating and sinking properties of various objects. In order to initiate a whole-class discussion a demonstration was conducted on the second day. During the demonstration, a large transparent container filled with water was placed on an overhead projector. Students were asked to predict what they thought would happen when various objects were placed in the water. The objects in question were two stones--a small (2 cm diameter) granite stone and a larger (10 cm diameter) pumice stone (The students did not have an opportunity to handle the stones.).

B: [With emphases] No! No! That's not right! That doesn't go with my mind [student grabs hold of head] it just doesn't go with my mind. (Project META, year 1, grade 1).

Example 2: Content. The next example is taken from a grade six word processed response to the following probes: "Last school year you spent a lot of time and effort trying to explain your ideas about the force or forces, if any, acting on the various items in the circus of motion activities. This school year you have had a chance to work with the same circus of motion activities. In your opinion, do you think your ideas about the force or forces, if any, acting on the various items in the circus have changed? If so, in what way have your ideas changed? Why do you think your ideas have changed? You may chose any item (s) from the circus to explain your current thinking."

Jill's Comments

My Past Ideas. In the past I thought for instance the BOOK ON THE TABLE had only 1 force, and that force was gravity.

I couldn't see that something that wasn't living could push back. I thought that this push back force wasn't a real push force but just an in the way "force," or an outside influence on the book.

However, my ideas have changed since the beginning of this year.

Sr. helped me to see the difference between the macroscopic level and the microscopic level, that was last year.

But I never really thought about that difference very much.

Then this year I began to think about the book on the table differently--

then [last school year] I was thinking on the macroscopic level and not on the microscopic level.

This year I wasn't looking at the table from the same perspective as last year.

Last year I was looking at living being the import focus and now I am looking at the molecules as being the important focus.

When I finally got my thoughts worked out I could see things from a different perspective. I found out that I had no trouble thinking about two balanced forces instead of just gravity working on the book.

It took me a whole YEAR to figure this concept out!!! Now I know it was worth THE YEAR to figure this out

because now I can see balanced forces everywhere! Balanced forces are needed to produce constant velocity!

The book on the table has a velocity of zero, that means it has a steady pace of zero.

Why, Sr. asks did my ideas change? I think my ideas changed because I have expanded my mind to more complicated ideas!

Like molecules in a table can have an effect on a book,

that balanced forces and unbalanced forces are a better way of explaining the cause of motion,

and that constant velocity and changing velocity are important things to look at when describing motion (Project META, grade 6, year 2--1992/93).

Classification

Sub-Categories

Reveals past theory

Reveals past metaphysical belief about the nature of living/non-living

Explicitly states change in ideas

Explains how ideas became understood

Compensation argument

Aware of shift in thinking

Compensation argument

Explains how ideas became understood

Reveals shift in focus of thinking

Acknowledges conceptual change

Reveals shift in metaphysical beliefs

Explicit reference to construction of knowledge takes time to achieve

Application of theory

Generalizes theory to new situation

Explains how ideas became understood

Reveals a metaphysical belief in the nature of molecules--they can cause an effect

Reveals an epistemological belief about the nature of an explanation

Reveals an epistemological belief that some things are more important to consider that others

Annotated comments. In the first case, Brianna (grade 1) refers to what she thinks will happen to the stone ("...both stones will sink...I know they'll sink"). She draws on her past experiences with casting stoned into the water to support her knowledge claim ("...I've seen lots of rocks sink...every time I throw a rock into the water...[it] always sinks"). Brianna goes on the reveal her metaphysical beliefs about the properties of water ("...water can't hold up rocks") and provides a simple analogy to support her claim ("..like it [the water] holds up boats). In addition, Brianna reveals the type of reasoning strategy she chooses to apply to this event--comparing the known to the unknown ("...if the little one [the smaller stone] sunk the big one's gotta sunk (sic)). When she is confronted with an anomalous event, Brianna reveals the reasoning she employs to claim the event should not have occurred ("...That's not right! That doesn't go with my mind. It just doesn't go with my mind.). Brianna clearly indicated that the event does not correspond to her personal way of thinking about the situation.

In the second case, Jill's response to probe statement demonstrates her ability to go beyond mere recognition of her personal constructs to comment on framework she uses to support her knowledge claims. She acknowledges that her ideas have changed during the course of the year. Jill is able to provide a contrast between her current and previous set of ideas ("...In the past I thought...the book on the table had only 1 force, and that force was gravity...I thought the push back force wasn't a real push force but just an in the way "force,"...[now I have] no trouble thinking about two balanced forces instead of just gravity..."). Jill reveals two strands to her reasoning. First, she considers the physics content and explains her understanding about the relationship between "balanced forces" and "constant velocity," ("...balanced forces are needed to produce constant velocity!..."). Second, she comments on why she thinks her ideas have changed over time ("...I think my ideas changed because I have expanded my mind to [include] more complicated ideas!). In addition, Jill shows evidence of coming to a qualitative understanding of the nature of her thinking ("...when I finally got my thoughts worked out I could see things from a different perspective. I found out I had no trouble thinking about two balanced forces...balanced forces and unbalanced forces are a better way of explaining the cause of motion, and that constant velocity and changing velocity are important things to look at when describing motion.").

Data analysis supports the claim that student statements do contain referenced to components of their conceptual ecologies.

Aim 2: Changes in Metacognition

The second goal of this study sought to characterize changes in individual studentís metacognitive capabilities over time. It was hypothesized that students who engage in metacognitive discourse become more sophisticated in their metacognitive capabilities over time. Data analysis clearly supports the view that individual students do change in their metacognitive capabilities from one year to the next. In order to substantiate this claim, an example of one student's (Jayne) classroom discourse about her understanding of the concept "idea" in second, third, and fourth grade respectively is provided.

Jayne: Year I. The following is an extract from a grade 2 transcript of a whole-class discussion. The focus of the discussion centers on the students' ideas about the meaning of the word "idea." The comments of one particular student, Jayne, are extracted from the comments of the class as a whole.

[I spent 3 to 5 minutes setting the context for the discussion. Jayne opens the discussion.]

Teach: ...how would you explain to a person that has never heard of the word idea...what idea means? Ok. Jayne.

Jayne: I would say (pause) its something (pause) a thought that you may do (pause) or you may not do. (pause) You may explain it to others (pause) maybe you just keep it to yourself.

[The teacher asks Jayne what she means by a thought.]

Jayne: I mean (long pause) its (pause) a picture in your head (pause) you see (pause)

[The discussion continues, several students try to clarify what they mean by the word idea. About 5 or six minutes later, Jayne attempts to express more on her thinking about the word "idea."]

Jayne: But if you thought about it that's an idea. (long pause) But no because (pause) how do you if you're just (pause) hum (pause) like if you're think of us (pause) or your just think of what we're doing or if we're (pause) or if you're thinking of doing something (pause) like if you've got to think ahead (pause) of the future [interrupted]

Teach: It's only an idea if I think about the future?

Stds: [Several] No.

Jayne: No. Well listen.

Teach: [Laughs] Ok. I'm listening very careful.

Jayne: Let's see (pause) let's say an idea is (pause) like I'm thinking that I'm going to (pause) hum (pause) <Paul: Drive a car.> No. I'm going to go over and sit down <t: Ok.> on the stool. That's is an ideas. That's an idea of something what you are going to do (pause) and that's an idea (pause) and that's how you do ideas <t: Ok.> but you don't say it out loud.

Teach: Two and two are five. That's an idea.

Stds: [Several] No.

Jayne: Two and two are four.

Thea: That's an idea. Two and Two are [with emphasis] four.

Teach: Two and two are five.

Jayne: Two and two are five is an idea but that's not what it really is.

Teach: Oh! You mean ideas can be wrong some times?

[Several students respond before Jayne responds to the above question.]

Jayne: Hum (pause) if you are asking (pause) if someone is asking (pause) asking a question and you say yes and it's really no that's your idea of what you think it is...

[Jayne gives an example involving a balloon that was mistakenly identified as a ball and claims "that's alright because that's your idea." Several students join in the discussion about right and wrong ideas. About 6 minutes later Jayne has something to add to the discussion.]

Jayne: ...you want another example?

Teach: Great! I'd love one!

Jayne: Alright lets say someone came up and asked you (pause) What do you think that air is made out of? Alright? [To teacher] You know what air is? [Teacher responds to her question, several students also respond.] Now (pause) and you said it was made out of (long pause) let say soap and water (pause) which it is not. Right? <t: [pretending air is made up of soap and water] But that's what I think!> But that was your (pause) that was what you think maybe they'll teach you (pause) but they're not going to say that is not right. <t: Why not?> Because it's your idea and they'll give you credit because <t: Who's they?> Well the people (pause) the person who asked you (pause) what air is made out of.

Teach: But I said that two and two is five and you all said no. You didn't give me credit for it.

Jayne: Though (sic) that was because it was your idea and that is good (pause) because it was your idea (pause) that is what you think. <t: But you don't agree with it?> Right. We don't agree with it. But maybe you do (pause) so then you keep on thinking.

Teach: But what if I went around earth saying I like your air a lot. It's is made out of soap and water.

Don: Then we wouldn't laugh.

Jayne: Then we would teach you.

Teach: What would you teach me?

Jayne: That air is not made out of soap and water.

Teach: Air is not made out of soap and water?

[The discussion continues as the students explain their ideas about the composition of air and what it means to teach someone.] (Project META, grade 2, year 1--1991/92)

Annotated Comments. During the recorded conversation, Jayne made explicit reference to what, in her opinion, constitutes an idea. ("...a thought you may do...not do...explain to others...[or] just keep it to yourself...its a picture in your mind"). During the discussion, she subsequently indicates that ideas are what individuals think about in a given situation ("...lets say an ideas is...like I'm thinking that I'm to go over and sit down...on the stool..that an idea...if someone is asking...a question and you say yes when it's really no that's your idea of what it is [you think]..."). As the discussion progresses, Jayne takes the opportunity to reiterate this point by giving another example. ("...Air is made out of soap and water which is not right but...that was what you think and no one is going to go against you with what you think...maybe they'll teach you but they're not going to say that's not right...they will give you credit"). When I ask Jayne "why" she did not give me credit for my statement "two and two is five" she indicates: that the idea is good but she and the rest of her peers do not agree with the idea ("...because it was your idea and that is good...that is what you think...we don't agree with it...").

Jayne: Year II. The following is an extract from a grade 3 transcript of a small-group audio-recorded discussion. Jayne and Don, are working together to produce a poster that encapsulates their explanation of the term "idea."

[During the first five minutes of the assignment the two students discuss organizational procedures. The discussion below picks up after the students have discussed their organizational procedures.]

Jayne: I think ideas are (pause) something like a picture in your mind.

Don: Me too! (pause) I think like (pause) like (pause) hum if you have something to think about the idea is in your head and you can keep it in your head or tell it to someone.

Jayne: Ok. Letfs write that down on the poster. [Discussion turns to talking and writing, long pauses during writing are eliminated for clarity.] Do you really think you can speak you ideas out of your head?

Don: I don't know I kinda think so. Do you?

Jayne: Hum (pause) I kinda don't know either. Like maybe yes and maybe no. (pause) <Don: What do you mean?> Like maybe I can speak my ideas to you <Don: Your doing it now aren't you?> Hum (pause) I don't know for sure. <Don: But I hear you telling me about your ideas I can hear you Jayne your talking about your ideas.> I know that. I just don't know if what you hear is my ideas or is just something like my idea. <Don: I don't get what you mean.> [Conversation is interrupted a third student who inquires about their poster.]

Don: [Discussion returns to task] Do you remember when we were doing this last year? <Jayne: No.> Yeah! Don't you remember? <Jayne: Guess not.> Yeah, sister was pretending she was ET <Jayne: Oh yeah!> and like every time someone tried to explain something she pretended like she didn't know anything like ET

Jayne: Yeah! That was funny. She tried to tell us two and two was five <Don: That's right.> and everybody kept trying to tell her two and two was four and that [interrupted]

Don: That's something that we can put on the poster don't you think?

Jayne: That sometimes ideas are good explanation of what is going on and that sometimes [Interrupted]

Don: And that some ideas are a better explanation than others like the posters on the wall [Referring to students' previous work displayed on the walls and ceilings.] My second poster is a better explanation than my first.

[Focus of the discussion shifts to content of posters that were displayed on the classroom walls/ceiling. Later, the two students return to the task at hand.]

Jayne: Ok. Hum (pause) we've got lots of things for the poster. <Don: only four different thing.> Is that all? I think we have a lot more. <Don: I'll write on scratch paper.> Ok. (long pause) Hum ok for number one, ideas are thoughts in your head and they are not right and they are not wrong they are just ideas. For number two some ideas are better than other like a better explanation <Don: not so fast.> Ok. (long pause) [Don reads back what he has written; then Jayne continues speaking.] and I think you use the ideas in your mind to think about other ideas because (pause)

Don: But sometimes the ideas in your mind don't let you think another way.

Jayne: Yeah! Like you said about the falling objects [Referring to Dons poster that depicts a heavier object falling at a faster rate than a lighter object.]

Don: I took me a long time to see (pause) see things different (pause) a long time. I wonder why?

Jayne: Maybe 'cause like you said (pause) ideas than you have in your mind (pause) cause you (long pause) I can't say it very good (pause) like you know hum (pause) hum you know what I mean <Don: Yeah. > Like maybe they interfere like maybe some ideas interfere with other ideas.

Don: That's what I think (pause) that's maybe why it took me so long to see why hum to (pause) to change my ideas about [Interrupted]

Teach: [checking with the group] Howfs it going over here?

Don: Good we got lots of good ideas.

Teach: [Laughs] Good ideas about ideas! It's like thinking about your thinking.

Jayne: That's awesome I like that (pause) thinking about your thinking. We were doing that with all the posters weren't we?

Teach: Un hum. You use your ideas to think about you ideas.

Don: On the posters I put my ideas about heavier things falling faster and Jayne and I talked about those ideas and had to use our ideas to talk about the poster ideas.

Jayne: [To teacher] Do you think Don really put his ideas on the poster (pause) like if the ideas are in Don's mind can they be on the poster too?

Teach: That's a very good question. What do the two of you think about that? (Project META, grade 3, year 2--1992/32)

Annotated Comments. Jayne provides evidence that she had consolidated her explanation of what constituted an idea. Her discussion with Don provides rich evidence of her epistemological beliefs about the nature of an idea. ("...ideas are thought in you head they are neither right or wrong they are just ideas...Some ideas are a better explanation than other ideas...I think you use your ideas in your mind to think about other ideas...Maybe some ideas interfere with other ideas..."). In addition, she attempts to probe deeper into her own thinking by questioning whether ideas can be transmitted between people. (..."Do you really think you can speak you ideas out of your head?...I kinda don't know either. Like maybe yes and maybe no...I just don't know if what you hear [my speech] is my ideas or is just something like my ideas.") This concept seems to be important to Jayne because after a forty-minute time lag [at the end of the class period] the question resurfaces again. She asks me ("...[with reference to Don's poster] do you think Don really puts his ideas on the poster...like if the ideas are in Don's mind can they be on the poster too?).

Jayne: Year III. The following is an essay written by Jayne in grade 4. As part of their regular assessment, the fourth grade students were given a choice of six different statements from which they could choose one to respond to. Jayne chose the following: "Over the past three years you have spend a lot of time and effort trying to explain your thinking about the term "idea." In your opinion, "What do you think ideas are?" "How can you best describe or characterize your ideas?" "Can you recall any specific examples of how your ideas might have changed over time?" "Why do you think your ideas have changed?" You may: (1) chose any one of the above questions, (2) chose a combination of the above questions or (3) respond to your own questions to explain your current thinking about the term "ideas." Jayne word-processed the following response:

My ideas about my ideas

I chose to write this essay about the importance of thinking about my own ideas.

My ideas are thoughts inside my mind. I can choose different ways of representing my ideas to other people. I can speak or write abont my ideas. I can illustrate them on posters. And I can draw concept maps to help me think abont how some of my ideas are linked together. All these are different ways I can represent my ideas. I don't think the ways I represent my ideas are the same as my ideas because my ideas are thoughts inside my mind. The thoughts on this page just stand for the thoughts in my mind. Sometimes I have a hard time telling about my ideas. I know what I think, it's just that I can't always say or write or draw exactly what I think. Other times I don't really know what I think and then I can't do anything with my ideas. But most of the time my ideas are intelligible to me and I can talk about them to other people.

My ideas are very important to me because that is what I use to think with. My ideas are not right and they are not wrong. They are just my ideas. Sometimes my ideas are a good explanation of what is going on and sometimes I have to change my ideas when I think they are not as good an explanation any more. I think that sometimes the ideas I have in my mind help me to think about things different and sometimes the ideas I have in my mind interfere with thinking about things different.

I changed my ideas about heat. I used to think that heat was something that flowed through things to make them hot. This was a very good explanation of why I thought things got hot like the metal rods and the wax experiment that we did this year. It took me a long time to think about the metal as the cause of the heat. I know I have changed my ideas. But I don't really know why I changed them. I just know that I have changed them.

I think that a better explanation for the cause of heat is that the molecules in the different kinds of things move very fast. The faster the molecules move the more heat the "thing" has. Not everybody agrees with my idea but that is ok. I know that Brianna thinks the same as me and so do Don and Jeff. We spend a lot of time talking about our ideas of heat and trying to make sense out of our ideas. All four of us think that molecules moving are a good explanation for what causes heat. But you had to come and asked us to thinking about how the sun warms the earth from 93 million miles away. Now I don't know what to think. I like my ideas about moving molecules. But I don't think there are moving molecules in outer space. Like between the sun and the earth. This is really hard! How am I going to be consistent! (Project META, grade 4, third year--1993/94)

Annotated Comments. In the third extract, Jayne (grade 4) reiterates many of her epistemological beliefs in the nature of an idea. She indicates explicitly that, for her, ideas are important vehicles of thought that can either help or hinder a person's perspective of a given situation. In addition, she indicated that: (a) ideas can change over time, (b) may be "linked" with other ideas, and (c) are capable of being applied to new situations. Lastly, Jayne provides evidence of her struggle to apply her current views about heat transfer to a new situation. She indicates that for her and a few of her peers, "moving molecules" are a causal mechanism for heat transfer. She has begun to doubt, however, the usefulness of her current ideas when applied to the radiant energy of the sun. Her epistemological commitment to consistency seemed to be the cause of her intellectual struggle (...I like my ideas about moving molecules...but I don't think there are moving molecules in outer space...This is really hard!...How am I going to be consistent!).

Comparison of Conceptions Analysis Scheme. Even though the three extracts presented above took place in a different settings (whole-class discussion, small-group discussion, and individual written response) Jayne's conceptions of the term "idea" in Year I can be compared with her conceptions in Year II and Year III. To carry out the analysis, a comparison of conceptions chart was developed to identify any recurring statements about the term idea. Figure 2 contains an example of a completed comparison of conceptions chart for Jayne.

Figure 2 About Here

The comparison of conceptions matrix displays a succinct summary of the Jayne's lengthy comments. In addition, the matrix allows important similarities and differences to be contrasted in a self-evident way. For example, Jayne understands that an idea is a thought or an image in the mind is consistently expressed from one year to the next. Yet her understanding that current ideas can be used to think about or interpret other ideas is expressed during the last two year of the study. Another particular example is Jayne's ability to distinguish between thoughts [properties of the mind] and representation of thoughts [in speech, text, illustrations] or relationships between thoughts [as expressed on concept maps] is expressed during final year of the study.

I assume the differences among Jayne's comments over the three years represents qualitative differences in her conceptions of the term idea. Thus, the pertinent question becomes: Is the noted change in Jayne's conceptual understanding linked to change in her metaconceptual sophistication? I believe the answer to this question yes. Several characteristics on the comparison of conceptions matrix when compared with the established metacognitive categories support this claim. First, the similarities in Jayne's metacognitive ability across the three years can be compared. Across all three years she is well able to articulate her understanding of the term ideas (conceptions category) and reveals the reasoning she uses to support her knowledge claims (reasoning category). With regards to components of her conceptual ecology, the only component that emerges across all three year is her attempt to give real world exemplars to support her knowledge claims. Second, the differences that emerge when comparing Jaynefs metacognitive statements across the three years are more indicative of a qualitative change in her metacognitive ability. For example, during Year II and Year III, Jayne clearly begins to consider the implications involved in her thinking about the term idea (implications category). Likewise, during Year III, she comments on the status of her thinking about ideas (thoughts that can be represented are intelligible; thoughts that cannot be represented are not useful). Other noted differences are linked to Jayne's conceptual ecology. During Year III, Jayne gives clear indication of her epistemological commitment to consistency when she tries to generalize her understanding of thermal transfer to a new situation. Likewise, her metaphysical belief in a kinetic explanation (moving molecules) for thermal energy is revealed.

It appears that there is an essential difference between Jayne's metacognitive ability with each succeeding year. Her ability to state her knowledge claims while using examples to support her reasoning is expanded, during Year II, to include her ability to consider the implications of her thinking. Furthermore, during Year III, her metacognitive capabilities are expanded to include comments on the status of her thinking and comments on the importance being consistent when generalizing from one context to another. Thus, the comparison of conception analysis reveals qualitative changes in Jayne's metacognitive capabilities that can be linked to qualitative changed in her conceptual understanding. The nature of the link between metacognition and conceptual understanding further explored in the section below.

Aim 3: Facilitating Change

The third goal of this study sought to explore the transparent links among pedagogical practice, enhanced metacognition, and conceptual understanding. By its philosophy, design, and manner of implementation, classroom practice provided ample opportunities for personal and group reflection and discussion. In addition, students were in the habit of collaboratively negotiating shared meaning for many of the terms used in classroom science work. These two practices were utilized as part of the analytical procedures. Step I of this phase-three analysis scheme compared individual student's initial understanding of the term intelligible with their final understanding of the same term looking for evidence of change in their conceptual understanding of the term.

The most striking findings drawn from the comparisons (Step I) relate to changes in conceptual understanding for the term intelligible. All eighteen grade four students began the process of collaborative negotiation with some intuitive understanding of the term intelligible; most of which were not in keeping with the standard dictionary definition of the term. At the end of the process, all eighteen students had a more in depth understanding of the term intelligible. Naturally, the form and extent of this development varied significantly across different individuals. Nevertheless, two common features transcended the individual differences. First, all eighteen students indicated, that for them, the term intelligible meant an idea or concept had to be understandable. Second, all eighteen students indicated it was necessary to have evidence that an idea or concept was understandable (i.e., something beyond mere say so). The most common evidence, noted by the students for evaluating intelligibility, was the notion of representativeness. For example, all students indicated that an idea could be represented through the spoken or written word or by using illustrations. Others included developing conceptual models, or giving real world examples. Students less frequently mentioned developing concept maps as a way of representing their personal thinking. Fifteen students stated it was necessary to have the "ideas behind the words" make sense. To illustrate the type of conceptual change that took place (with regard to the term intelligible), the work of one student, Kelly is included in Table 1.

Table 1 About Here

Step II of the analysis scheme provided almost seven hours of videotape covering nine class periods. All seven hours of videotape were viewed and transcripts were made of sessions three, six, and nine respectively. Interpretive summaries were made of these three sessions (Step III). To provide the reader with a sense of how young children (Grade 4, ages 9-10) go about negotiating meaning, two segments of student discourse are provided below. The segments below are taken from the first six to eight minutes of sessions three and six. They are highly representative of the type of discussion that took place during the entire negotiation process.

Several items are worth noting. First, the students are involved and interested in each otherís comments. Second, they are able to maintain, over a significant period of time, a student-to-student discussion without filtering all comments through the teacher. Third, during the negotiation process the students frequently employed different conceptual strategies which, in most instances, reflect the established classroom learning goals (viz., state explicitly their own views, consider the reasoning used to support their views, consider the implications of their views, etc.) This is worth noting because it provides evidence that the learning goals were in operation and not merely a list of suggested practices on paper.

Context. The student in Grade 4 began the process of negotiating meaning for the term intelligible by creating individual posters in response to the probe: What does the term intelligible mean to you? The students shared the content of their posters in both small and large group settings (Day 1). During science class the following day, the students looked for patterns among the ideas represented on the various posters, created a list of noted patterns, and began a discussion about the content of the list (Day 2). The excerpt below is a short segment from the audio taped discussion that took place on Day 3.

Day 3: Negotiation Process

Teach: Yesterday you were trying to build an understanding for this word [refers to word intelligible on poster].

Ali: There is a lot of meaning for the word.

Heath: You can say a lot of things about the word.

Ali: Yeah! There are a lot of things you can say and explain about it.

Teach: Ok. So (pause) hum (pause) and that's were we left off trying to say something about this word. Hum (pause) the thing is (pause) Do you think that just saying something helps you understand it?

Class: [Several voices] No. Not always.

Teach: What do you mean by [interrupted]

Adam: Like picture...Sometimes pictures in your mind [interrupted]...

[One student attempts to say what he thinks about including the phrase "picture in you mind." In the process of trying to express his ideas, he realized that he is unable to do and says so. The discussion picks up with one student inquiring "why" this is so?]

Bliss: Why?

Ali: Maybe because there in pictures (pause) and not in clear pictures yet.

Adam: There not always like in clear pictures yet. Like you haven't yet really found (pause) like the rights words or the whole paragraph or even the sentence yet.

MichQ: That's why we draw pictures when we want to explain something because we can't find the words yet. [To teacher] You always give a piece of paper to draw [interrupted] (several talking at once)

Bliss: And we use models too. (Several students all talking at once.) Models are good because models already come in some kind of shape, and pictures, you have to draw it yourself and sometimes your not good [interrupted]

Ali: Yeah. But I don't think a model is the only thing you need. I think the models need to stand for ideas.

Adam: Maybe like, (pause) it's like, (Pause) Maybe Allison like it's a different kind of model that Bliss is talking about. I think Bliss means like the kind of models that are up on the shelf, like the eye and like the ear. And I like, think that like, you are describing something, like (pause) like when you are saying something, like a model of what you are thinking (pause) like a model the stand for your thoughts and like that's a different kind of model.

Kath: Ok. But were getting off the word intelligible. Can we get back to that word? Like I would like to talk what about what intelligible means because without a meaning it's just a non-usable word.

MichQ: I think it means to understand.

[Several students comment on whether the term "understand" is a useful way to thinking about intelligible. The discussion picks up with the teacher changing the direction of the conversation.]

Teach: On you list yesterday you also put the words make sense. Somebody said yesterday that we should take that [words make sense] out of there, take it off the list.

Voices: S-1: But I like that one. S-2: And I like that one. S-3: I do too.

Eamon: You can't take it off because I think they go together. I don't think you should take it off. Why do you want to take it off? I don't remember who suggested we should take make sense off this list yesterday, but they did give a reason.

David: It was somebody like (pause) like (pause) I think it was Kathryn. Or maybe it was Michelle.

Ali: Yeah! I remember that for some reason we wanted it [make sense] on the bottom and not on the top list.

Adam: I don't remember exactly why but I think it was because they think that makes sense is the same as understand. Like if a teacher says something to you, like to actually make something out it, you have, like it has to make sense to you.

Eamon: Like a lot of this stuff is kinda connected to each other. They are kinda like somehow meaning the same thing. Remember when we put the word idea on the floor and we had little cards. And we got to write all the other words that you wanted to go with the word idea. Some of the same words we wrote for idea are coming into this discussion.

Std: I wrote concepts. [Several students calling out] Theory, thoughts, think, what you know, experiences, drawing, pictures in your mind, theory, intelligible, intelligent

Eamon: Somebody just put the word intelligible with the word idea and I don't think [I] heard anybody do that before. I saw one group with intelligent but I put intelligible and I don't think the words are the same [interrupted]

Chel: But we're getting away from makes sense. You know like yesterday when you were saying Spanish to us that didn't make sense. And I think that word should really be here as part of understanding and not on the bottom of the list.

Ali: Maybe you right. Like maybe if you really don't know your idea well enough then it doesn't really make sense to you.

MichQ: Intelligible and to understand all go with like ideas. So we should have had like (pause) some of us didn't have like intelligible or understand with the word ideas and like I think we should put it on the cards to go with the word idea 'cause I mean that goes with ideas.

Bliss: But to understand and make sense, like hum (pause) they don't go together because you could understand something but not...but it could not make any sense.

David: Like curtains eat. Let me try to find something else besides curtains eat. Do you know what school is?

Voices: Yes. S-1: We're in school [Laughs].

David: Ok. How about the words school swims? [Several talking at once]

Teach: Ok. Please talk one at a time. School swims.

Stds: I doesn't make sense.

Ali: We know the words but when you put them together it's not intelligible to me because it doesn't make any sense.

Teach: But why doesn't it make any sense? It's the why we are trying to get at. Why doesn't it make any sense?

Andy: I understand it but it doesn't make sense because a school can't move let alone swim

Kevin: Because it doesn't click in my head.

David: What do you mean doesn't click in your head?

Kevin: Like, (pause) like just it (pause) it just doesn't (pause) 'Cause it just doesn't go with what I already think. It doesn't make an idea that's (pause) that's sensible.

Teach: Ok, that one way of saying it, it doesn't click in your head. Does somebody else want to say something? Ok.

Nick: It doesn't make sense to me because it's almost impossible.

Kevin: It is impossible!

Nick: its not logical schools just can't behave that way.

Adam: Like if you have a thing to pick up the school and put it in the water it will just weigh so much it would sink. And besides you can pick up a school and put it the water in the first place [interrupted]

Eamon: It doesn't have any energy.

Adam: Right Eamon. It doesn't have any energy to move. Like swim move.

Melinda: Besides schools are dead. [Several are talking all at once].

Teach: Ok. One at a time pleases.

Kath: You haven't heard it before and you haven't had a chance to think about it.

Kelly: But even if you did think about it schools wouldn't have the ability to swim because it's made of rock and heavy things and it would and (pause) hum (pause) most rocks usually sink.

Teach: May I ask you something here? Is schools swim sort of analogous to curtains eat? [Several voices] Yes. Yeah.

MichQ: ...Well, the word school makes sense and the word swim makes sense. But the words school swims they don't go together because you can't attach them.

Adam: Yes you can: schools swim.

MichQ: Not without meaning you can't [Several talking at once]

Melinda: Like I don't picture a school having arms and legs going stroke, slash. [Laughs]

Eamon: But you can picture it. I can imagine a school with arms and legs swimming I could even draw it.

Melinda: But Eamon, that 's not even a sensible idea.

Eamon: That what I'm trying to say. You can imagine that idea. So I don't think just because you can picture something in your mind that itfs intelligible. (Pause) Like do the words school swims communicate a sensible idea? [Several responding] No

Eamon: You could draw a school and you could draw arms and legs on the school and you could draw water all around the school then you would get the idea of a school swimming. But it's not something you have ever seen or really experienced or stuff like that.

Annotated Comments. The session opens with Allison and Heather stating their individual views ("...there are a lot of meanings for the word [intelligible]...there are a lot of things you an say and explain about it."). The discussion quickly centers on the inability of one student to express the content of his thinking and what he meant by the phrase "picture in the mind." Allison indicates that perhaps the inability to express one's ideas lie in the fact that the ideas are not clearly understood. ("...Maybe because...[ideas] are not in clear pictures yet...) Adam, however, indicates that he thinks the problem lies in language construction ("...you haven't found the right words or the whole paragraph or even the sentence yet."). Michele and Bliss relate this statement to classroom practices ("...that's why we draw pictures...and we use models too... [referring to physical models]. Allison takes exception to Bliss' statement about the use of models and states that models "need to stand for ideas." Adam, considers the implication of both Bliss' and Allison's comments. In doing so, he provides evidence that he is able to distinguish between physical and conceptual models. ("...[Directing his comments to Allison] Bliss means the kinds of models...like the eye...you are describing...something like a model of what you are thinking...a model that stand for your thoughts and like that's a different kind of model.).

Kathryn attempts to redirect the discussion to considering the meaning of the term intelligible. In doing so, she reveals her epistemological belief about the value of determining meaning. ("...because without a meaning it's [the term intelligible] a non-usable word.) I raise the question whether the phrase "makes sense" should remain on the list of descriptors for the term intelligible. There seems to be confusion among the students as to who suggested the phrase should be removed from the list.

Eamon shifts the direction of the conversation by referring to a previous exercise [construction of a concept map for the term idea] and states that "some of the same words we wrote for idea are coming into this discussion." The class seems to agree with his statement and begin to call out different words used in constructing their concept map for the term "idea." Eamon notices that someone in the group has "connected" the term intelligible with the term "idea;" and in his opinion, this is a new connection.

Several segments of the discourse illustrate how the students go about trying to determine the relationship between the term intelligible and the phrase "makes sense." David generates an example for his peers to consider: "schools swim." Several students indicate that both the words "school" and "swim" are intelligible; but, object to the concept of stringing the words together. At this point, the students offer several reasons for their objection. ("...We know the words but when you put them together it's not intelligible because it doesn't make any sense (Ali)...Because it doesn't click in my head...it doesn't go with what I already think...it doesn't make an idea that's sensible (Kevin)... It doesn't make any sense to me because it's almost impossible (Nick).

The remaining segments of discourse reveal components of the student's conceptual ecology. For example, several students reveal their metaphysical beliefs about the nature of a building. ("...A school can't move let alone swim (Andy)...It's not logical schools just can't behave that way (Nick)...If you...pick up the school and put it in the water it will just weigh so much it would sink. And besides you can't pick up a school and put it in the water in the first place...it doesn't have any energy to move. Like swim move (Adam)...Schools wouldn't have the ability to swim because it's made of rock and heavy thing...most rocks usually sink (Kelly). Lastly, Eamon shifts the discussion to consider the implication of "picturing something in your mind." ("...I can imagine a school with arms and legs swimming. I could even draw it...So I don't think just because you can picture something in your mind that it's intelligible. Like does the words school swims communicate a sensible idea?").

The entire session, when taken as a whole, provides evidence that the collaborative construction of meaning can successfully be negotiated by young children. Likewise the transcript provides evidence that these negotiations, at times, include different facets of the students metacognitive capabilities.

Context. The following extract is a continuation of the above discussion that took place three days later (session 6).

Day 6: Negotiation process

Teach: During the past week or so you have all been working hard to find a way to come up with an agreed upon meaning for word intelligible. You have asked yourselves many questions. For example, How do you know when you understand something? or When is something understandable? or as the case may be, How do you know when something is intelligible?

Kathryn: I think we have agreed on many things like we know an ideas is intelligible when we can picture the idea in our mind, or explain the idea that we are thinking about to other people.

David: And we said that an ideas is intelligible (pause) when we can find different ways of representing it like writing about it or building a model that stands for the idea and I think we agreed that [interrupted]

Eamon: Don't forget about using analogies, David

David: I was just going to say that (pause) that (pause) an analogy is making a comparison between two things and I don't think you can make a good comparison if you don't have an intelligible idea in the first place.

Eamon: And we spent a lot of time talking about if it is important for an idea to make sense.

Bliss: But I don't think we all agree on this one do we?

Kevin: But I think what we do agree on is that the words and the pictures [mental images] we get from the words hafta make sense.

Class: [Several responding] Yes. That's right. [Several talk all at once].

Eamon: But I think it is the ideas that have to make sense (pause) the ideas behind the words and not just the words.

MichQ: That's right! But who's ideas need to make sense? Like mine or yours? Like if my ideas don't make sense to me that is really (pause) like something major. If your ideas don't make sense to me that's different.

Eamon: Yeah! Like sometimes other people's ideas are not intelligible to me but if my own are not intelligible to me that's major alright because I can't even explain what I mean until my ideas are at least a little intelligible to me.

Kevin: I think that's important (pause) the difference between understanding my ideas and understanding your ideas. My ideas usually make sense to me and if they don't I just stop talking. But lots of times other people's ideas do not make sense to me (pause)

Teach: Would you say their ideas are unintelligible to you?

Kevin: Not really (pause) I'm not sure (long pause) Can you come back to me later?

Ali: Maybe Kevin the ideas are intelligible but you just don't believe in them. Is that what you are thinking about.

Kevin: Maybe (pause) like (long pause) knowing and understanding something is different than believing in something. Like I know what I used to say caused the seasons when I was in third grade and I can understand what I wrote about the causes of the seasons but I don't believe those explanations anymore.

Kathryn: I think we will have to have another word to stand for believing something or not (long pause) a word that is different that intelligible because if we don't we are going to get mixed up between talking about understanding and believing something.

Kevin: That's my problem sometimes I think that makes sense goes more with believing something than understanding something.

Class: [Several responding] Me too. So do I. (Several all talking at once)

Teach: Do you think it might be profitable to try and distinguish between understanding and idea and finding that idea believable? [Several voices] Yes.

Teach: What if on the very first day we began this work, I just told you the meaning of the word intelligible.

Class: [Several voices] No. You'd never do that! I don't think so. [Several voices all talking at once.]

Teach: Could we please go one at a time. Ok. Melinda.

Melinda: Like a lot of discussion time when into making intelligible mean something and I think that is important because just telling us the meaning of a word doesn't make it intelligible. I think it is important to think about your ideas and when you are making meaning for words you are thinking about your ideas.

Chel: I think its important to think about your ideas too and like if you told us the meaning of intelligible we could have saved a bunch of time but we would not really understand the meaning of the word. [Several voices] That's right! Yes.

Kelly: And I think knowing what I think or believe about something can help me better understand and make sense of my ideas.

Andy: And if I know about my ideas I can better learn something like I have control. And I think that is your job to help us understand something and not just to tell us what to say or what to believe.

Annotated Comments. Several things are worth noting. First, the students have begun to consolidate their ideas about the meaning of the term intelligible. ("...I think we have agreed on many things (Kathryn)... And we say that an ideas is intelligible when we can find different ways of representing it like writing about it or building a model that stands for the idea (David)).

Second, a consensus is beginning to develop among the students. Several students express the group's position on the term intelligible. They do so without other members of the class expressing disagreement. ("...An idea is intelligible when we can picture the idea in our minds or explain the idea to others (Kathryn). An idea is intelligible when we can find different ways to represent itÖ like writing about it or building a model that stands for the idea...or using analogies. An analogy is making a comparison between two things and I don't thing you can make a good comparison if you don't have an intelligible idea in the first place (David)ÖThe words and the pictures [mental pictures] we get from the words have to make sense (Kevin)). It is apparent from the discourse that the group concurs with the above positions (If a consensus was lacking, individual members of the group would have voiced their concerns).

Third, there is a sense that the term intelligible can be applied to both personal constructs and someone else's constructs ("...But who's ideas need to make sense? Like mine or yours? Like if my ideas don't make sense to me that is really like something major. If you ideas don't make sense to me that's different (Michele)...Like sometimes other people's ideas are not intelligible to me but if my own [ideas] are not intelligible to the that's major. Because I can't even explain what I mean until my ideas are at least a little intelligible to me (Eamon...I think that's important the difference between understanding my ideas and understanding your ideas (Kevin).

Fourth, the students provide evidence of their ability to differentiate between "understanding" an idea and "believing" in an idea ("...knowing and understanding something is different than believing in something (Kevin)). The students take this conceptual distinction a step further by indicating the need to come up with a term to represent the notion of believing. ("...I think we will have to have another word to stand for believing something or not... A word that is different from intelligible because if we don't we are going to get mixed up between talking about understanding and believing something (Kathryn)"). These types of comment are a good indication to me that the students are conceptually ready to deal with the term plausible.

Lastly, several students reveal their epistemological beliefs in the value of developing meaning for terms in general. ("...I think that is important because just telling us the meaning of a word doesn't make it intelligible and I think it is important to think about your ideas and when you are making meaning for words you are thinking about your ideas (Melinda). ...I think knowing what I think or believe about something can help me better understand and make sense of my ideas (Kelly)...And I think that is your job to help us understand something and not just to tell us what to say or what to believe (Andy)).

Step IV of phase-three analysis scheme supports the claim that there is a correlation among observed pedagogical practices, the types of metacognitive statements produced by the students, and their conceptual understanding.

Table 2 About Here

The conceptual strategies employed by the students are reflected in their metaconceptual statements. For example, when students: (a) attempt to make public their individual knowledge claims; (b) offer explanations to support their constructs or beliefs; or (c) attempt to consider the implications of their personal constructs or beliefs the types of metaconceptual statements produced are reflective of these conceptual strategies. Likewise, when students engage in the above practices which include evaluating the consistency and generalizability of their beliefs, or explicitly considering the status of their conceptions they are, in effect, laying out their conceptual understandings as objects of cognition. Thus, metacognition seems to be inherent in the process of conceptual understanding.

Conclusions and Discussion

The aim of this study is to provide insight into the types of metacognitive thought the young students in SAS (grades 1 ñ 6) are capable of representing. My intent is to illuminate the nature of metacognition, per se; characterize the process by which individuals change their metacognitive capabilities; and explore the relationship among pedagogical practice, metacognition, and conceptual understanding. In this paper I have outlined in some detail the process of analysis of students' metacognitive discourse and exemplified the analysis using excerpts produced by the elementary students. The process provides important findings that can be interpreted from multiple perspectives. These finding include the following.

Aim 1: Nature of Metacognition

The categorization process used during *Phase-One Analysis Scheme* provides insight into the nature of metacognition and illuminates the multidimensional facets of higher-level metacognitive thought.

First, metacognitive ability is very subtle; a great deal of it rests on sensing states of mind and having a language to describe states of mind. The students' natural language contains a rich commonsense vocabulary for the phenomena of thought. At times, it is difficult for them to think of specific vocabulary to describe their states of mind without in some way utilizing metaphors drawn from the physical world. For example, students frequently speak about *finding* support for an argument, *retrieving* a piece of information, or *linking* ideas together. Even these terms hardly do justice to mental events the students wishes to describe. When describing mental events, the students in this study frequently give anthropomorphic attributes to the physical world (e.g., intention). With metacognitive sophistication, however, students begin to articulate that the anthropomorphic attributes are language devise employed describe their thoughts.

Second, elements of metacognitive thought are graded, in the sense that some are much more prominent in the system than others. In fact, one can distinguish two levels of this grading or priority structure:

1. A *representational level* óan inner awareness of one's own unobservable constructs (internal representations) made public through verbal discourse, writing, use of illustrations, or conceptual models (external representations);

2. An *evaluative level* óan ability to draw inferences about one's own unobservable constructs. For example, the ability to consider the implications or limitations inherent in personal knowledge claims, refer to thinking-learning processes, comment on status, or to refer to components of oneís own conceptual ecology (specifically consistency and generalizability).

I believe the development of metacognitive thought during instruction is in large part a shifting and rearrangement of these levels according to how useful the elements are in the development of conceptual understanding.

Third, results from this study stand in mark contrast to earlier studies on students' metacognitive ability. In several studies the authors conclude that metacognitive development begins during late adolescence. Few studies, if any, suggest that the issue is important for young children. Data from this study provides evidence that metacognitive sophistication is within the capabilities of young school age children. What is even clearer, form this study, is that elementary school science programs can be good soil for metacognitive development.

Aim 2: Changes in Metacognition

The comparison of concept process used during *Phase-Two Analysis Scheme* provides evidence that studentsí metacognitive abilities change over time. The data leaves one with the impression that a change in metacognitive ability coupled with concomitant changes in conceptual understanding (viz., of the term idea) is a natural process of a developmental stage. I do not believe these changes reflect a stage of development in the Piagetian sense. Neither do I believe that the changes in metacognitive sophistication reflect some other, more abstract, cognitive ability of the child. Along similar lines, it is possible to interpret aspects of change in metacognition and concomitant conceptual understanding as a matter of development of the student's intellectual style. In some respects, this may be true. Yet, I resist the temptation to think of these differences as intrinsic characteristics of individuals. The strong claim I wish to make is that changes in metacognitive ability and conceptual understanding may be more closely linked to the individual student's epistemological stance. For example, a view of knowledge that is much more tentative in nature (i.e., consisting of a view of knowledge that is appreciative of the value and danger inherent in one's own knowledge claims) is more likely to reinforce the development of ideas to the point where they could provide even greater leverage for learning. The best guess that I can make at this point is to assume that if I change students' educational experiences in a significant way, there is every reason to believe that they will be concomitant change is metacognitive ability. Likewise, changes in metacognitive ability may be more closely linked to changes in epistemological position (i.e., with more productive models of knowledge development). Providing evidence for this hypothesis must be reserved for future research.

Aim 3: Facilitating Change

The theme analysis process used during the *Phase-Three Analysis Scheme* provides evidence that the pedagogical practices at work in the educational environment are linked to observed changes in metacognitive sophistication. Likewise, the observed changes in metacognitive sophistication are linked to observed changes in conceptual understanding. The open question is: What is the nature of this link?

One source of evidence relevant to the issue is the success of current pedagogical practices designed to foster changes in metacognition sophistication. I assume, but at present have no direct evidence for my assumption, that metacognitive sophistication is embedded in a wider context of pedagogical practice. Insofar as the pedagogical practices framing this study are sound, the students' ability to engage in multiple facets of metacognition could suggest a highly supportive relationship between practice and ability. Data from this study does not, however, provide evidence of a straightforward one-to-one correspondence between specific practices and metacognitive ability and it certainly does not provide evidence of a causal nature.

Even though the data does not support the conclusion of a "cause and effect" relationship, important aspects are noted within the data. First, metacognitive ability is important in its own right; and seems to be an integral component of conceptual understanding. Second, metacognitive sophistication can be gained by actively engaging in the process. Third, both metacognitive sophistication and conceptual understanding need to be supported by a pedagogical approach that emphasizes reflection on and evaluation of personal knowledge claims. Lastly, the pedagogical practices employed during Project META may be so intertwined with metacognitive development that it may be impossible to tease apart the two components. For example, metacognitive development begins with:

1. simple statements about knowledge claims supported by reasoning,
2. develops to a level in which more complex criteria are recognized as necessary in assessing knowledge claims (e.g., implications of knowledge claims, status of knowledge claims); and
3. progresses to a level where the learner expresses a commitment to a world with many frames of reference and relative validity (e.g., revealing epistemological and metaphysical beliefs and commitment to consistence or generalizability).

It is obvious that the pedagogical practices underpinning Project META were similar in nature.

Lastly, I believe that it is fair to say that "time scale" is an important parameter in the development of both metaconceptual sophistication and conceptual understanding. Project META is a three-year study. I feel comfortable hypothesizing that significantly different results may have emerged if the study consisted of a single year or less. Many key phenomena observed in this study (i.e., coming to understand, the effect in a shift of perspective, or the process of gradually building insights) takes a significant among of time at being metaconceptual. Likewise, the pedagogical practices at work with the educational environment take a significant amount of time to develop. For example, the practice of having the students engage in negotiating definitions in the way the science community does it requires that a significant amount of educational time be set aside to accomplish this task. Without the time to negotiate meaning, however, the students would be at risk of developing a more naive epistemological perspective on the nature of science--definitions are not negotiable, nor is knowledge and understanding something that is created.

Instructional Implications

Several important instructional implications can be drawn from the results of this study. First, an epistemologically sound practice is to create a teaching-learning environment that encourages students to inspect and evaluate the content of their mental constructs (i.e., intellectual model building becomes the central focus of instruction). This recommendation stands in direct contrast to pedagogical practices that require students engage in straightforward recall of facts about the physical world.

Second, explicitly promoting metacognition within the science classroom is not a simple straightforward task. Even in the best constructivist learning environment metacognition does not simply happen, it must be explicitly promoted. The choice to do so should be guided by the fundamental conjecture that metacognitive ability is built from self-made observations of the structure of one's own knowledge claims and personal intellectual functioning. Thus, I propose the task of promoting metacognition within a learning environment is largely one of providing better conceptual models and experiences from which students can abstract. To be sure, it is important to teach some explicit notions and terminology of science, but it is just as important to respect the essentially personal nature of the construction of knowledge.

Third, in my opinion, it is never appropriate to separate the task of developing knowledge from the context of building conceptual understanding. The notion of conceptual understanding, however, has not yet been unpacked to the point that it is a legitimate framework for guiding classroom work and assessment. I believe the implicit strategic decisions one employs are largely linked to the educational context or situation within which one works. For example, how an educator goes about promoting metacognition and conceptual understanding among secondary or tertiary students (in which objectivism is the predominant or only epistemology available to them) may be significantly different from how an educator goes about promoting metacognition among younger students who have not been enculturated into a single view of knowledge.

Summary

The findings from this study significantly add to our understanding about the nature of metacognition. First, higher-level metacognition is multifaceted in nature, and is important to learn. Even though metacognitive thought is very difficult to study, the classification scheme developed for this study suggests a beginning point. Second, the type of educational environment created for students to learn within can be supportive to conceptual understanding. In this paper, I have outlined a series of pedagogical practices, which have both altered the students' metacognitive sophistication and conceptual understanding. The system as a whole, however, may well be defined and guided by the studentsí general epistemological stance toward knowledge that has significant consequences for which things are learned and which are not.

I began this paper with the conjecture that higher levels of cognitive activity are important to learning and intellectual ability. But for this grandiose claim to have substance, we as researchers in cognitive psychology and science education need some sense of what it means to "think better" and "conceptually understand" science. There is little empirical evidence on this point. Before such studies can be designed, however, we will need an accurate and detailed description of type of metacognitive functioning that is necessary for students to achieve a shift in perspective and how important that shift can be. Likewise, before such studies can succeed, we will need a detailed description of students' epistemology stances, as well as details of pedagogical practices that advance their epistemological views. In this paper, I have sought to contribute both to a description of metacognitive functioning and to a description of pedagogical practices that promote that functioning. What remain for future research are detailed descriptions of students' epistemological stances, as well as details descriptions of pedagogical practices that enhance students' epistemological views.

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Endnotes

[1] Throughout this article, *conceptions* is assumed to be analogous to concepts, propositions, and theories. I recognize the important distinctions inherent in these terms, but have chosen to side-step a fuller explanation to focus on characterizing what can be internally represented. That internal representations might connote something the size and complexity of a concept (acceleration implies a force), a proposition (acceleration is directly proportional to the unbalanced force ad inversely proportional to the mass of the object) or a theory (general / specific theory of relativity) is not germane to this research.

[2-3] The terms *internal representations* and *external representations* has been employed by Thorley (1990) to signify what can be cognitively represented. For Thorley, both internal and external representations refer to the nature and function of a conception. He goes on to indicate that conceptions are "internal qualities of the mind which structure experiences." Excluded from his definition is the out-there-ness of teacher talk, books, or laboratory exercises; that is, conceptions are not "the currency of exchange between teacher and student." Thus, internal representations refer to the action of an individual who uses his or her conceptions to construct a mental representation (internal) of that conception. This mental representation can, if desired, be generated into an external representation by voice, writing, and so on.

[4] Hands-on science refers to instruction designed to engage students in reasoning that requires them to think about and look for consistency and generalizability in constructing new knowledge. This instructional design is not to be confused with merely giving students a set of activities without a corresponding connection with any scientific theory or principle. To do so would lead to isolated bits of factual information or skills which, in turn, could not be applied by the learner in an intellectually fruitful way.

[5] The authors of the conceptual change model (Posner, *et al* ., 1985) identified the components of the conceptual ecology as: (a) anomalies, (b) prototypical exemplars and images, (c) past experiences, (d) analogies and metaphors, (e) epistemological commitments, (f) metaphysical beliefs, and (g) other knowledge. Beeth (1993b) argued that it was highly unlikely that students would give direct evidence for these components of their ecologies in even a small number of instances. He hypothesized, however, that reasonable inferences about these components could be drawn by a researcher if instruction was designed to challenge students to examine specific components of their conceptual ecology.

Table 1

Transcript of Pre-Instructional and Post-Instructional Comments for the Term Intelligible for Kelly-Grade 4

Comments for the Term Intelligible for Kelly

Pre-Instructional Comments: From Poster Drawing

Probe: What does the word intelligible mean to you?

Kelly drew a head. Over the head the she drew a large thought bubble with the caption:

> "I have never heard of the word intelligible but it might have something to do with intelligence. I think it mean smart and knows a lot."

Around the head and thought bubble she drew several question marks of varying sizes.

Project META, Grade 4, Year 1--1991-92. (3/22/92)

Post-Instructional Comments: Word Processed Document

Probe: You have been working on a way to describe the word intelligible. If you had to write an explanation for the word intelligible, what would you write?

> "I would say the word intelligible means that you can understand an idea. Let me give you an example. Ok like when someone comes up to you and tells you their ideas about heat transfer. You might understand it or you might not. The explanation that you understand is intelligible for you and the explanation is intelligible for the person telling you or they can not tell you their ideas. And when you understand an idea you can do more than just say you understand it like you can represent it by explaining it or writing about it or drawing pictures. And you can build models that stand for an intelligible idea. And I think the ideas behind the words or phrases that you say have to make sense. That is what I would say about the word intelligible." Project META, Grade 4, Year 1--1991-92. (4/1/92)

Annotated Comments

Kelly's response to the initial probe is limited to guessing about the meaning of the word intelligible. She readily acknowledges that she never heard the word before the this instance. Her response to the second probe is much more enlightening. For intelligible, Kelly provides evidence that her understanding is more complete an extensive than before.

Table 2

Partial Transcripts of Discussion Among Students to Construct Meaning for the Term Intelligible: Relation Among Students' Comments, Inferred Conceptual Strategies, and Metacognitive Categories.

Comments	Inferred Cognitive Strategies
ï There is a lot of meaning for the word. ï You can say a lot of things about the word. ï Yeah! There is a lot of things you can say and explain about it. [metacognitive category: conceptions]	ï Stds state personal claims

ï Why? ï Maybe because there in pictures (pause) and not in clear pictures yet. ï There not always like in clear pictures yet. Like you haven't yet really found (pause) like the rights words or the whole paragraph or even the sentence yet. [metacognitive category: reasoning]	ï Stds consider reasoning to support claims
ï That's why we draw pictures when we want to explain something because we can't find the words yet. [To teacher] You always give a piece of paper to draw [interrupted] (several talking at once) ï And we use models too. (Several students all talking at once.) Models are good because models already come in some kind of shape, and pictures, you have to draw it yourself and sometimes your not good [interrupted] ï Yeah. But I don't think models is the only thing you need. I think the models need to stand for ideas. [metacognitive category: implications]	ï Stds consider implications of actions
ï Maybe like,...it's like...Maybe Allison like it's a different kind of model that Bliss is talking about. I think Bliss means like the kind of models that are up on the shelf, like the eye and like the ear. And I like, think that like, you are describing something, like...like when you are saying something, like a model of what you are thinking (pause) like a model the stand for your thoughts and like that's a different kind of model. [metacognitive category: implications]	ï Stdt considers implication of peer's claims
ï Ok. But were getting off the word intelligible. Can we get back to that word. Like I would like to talk what about what intelligible means because without a meaning it's just a non-usable word. [metacognitive category: conceptual ecology]	ï Stdt redirects discussion; reveals epistemological belief about the value of determining meaning
ï Like a lot of this stuff is kinda connected to each other. They are kinda like somehow meaning the same thing. Remember when we put the word idea on the floor and we had little cards. And we got to write all the other words that you wanted to go with the word idea. Some of the same words we wrote for idea are coming into this discussion. I wrote concepts [Several students calling out] Theory, thoughts, think, what you know, experiences, drawing, pictures in your mind, theory, intelligible, intelligent ï Somebody just put the word intelligible with the word idea and don't think head anybody do that before. I saw one group with intelligent but I put intelligible and I don't think the words are the same [interrupted] [metacognitive category: conceptual ecology]	ï Stdts reveal epistemological beliefs about the relationship among various concepts and the term idea
ï But to understand and make sense, like hum (pause) they don't go together because you could understand something but not...but it could not make any sense. [metacognitive category: conceptual ecology]	ï Stdt reveals epistemological belief about the relationship between the term intelligible and the concept understand
ï Like curtains eat. Let me try to find something else besides curtains eat. Do you know what school is?...Ok. How about the words school swims? ï I doesn't make sense. ï We know the words but when you put them together it's not intelligible to me because it doesn't make any sense. [metacognitive category: reasoning; reference to status is beginning to emerge]	ï Stdt poses problem for peers consideration; peers state claims about intelligibility of problem

ï A school can't move let alone swim ï It's not logical schools just can't behave that way ï If you...pick up the school and put it in the water it will just weigh so much it would sink. And besides you can't pick up a school and put it in the water in the first place ï It doesn't have any energy to move. Like swim move ï Schools wouldn't have the ability to swim because it's made of rock and heavy things and it would...most rocks usually sink [metacognitive category: conceptual ecology]	ï Stdts reveals metaphysical beliefs bout the nature of a building

ï I can imagine a school with arms and legs swimming. I could even draw it..So I don't think just because you can picture something in your mind that it's intelligible. Like does the words school swims communicate a sensible idea? [metacognitive category: implication; reference to status is beginning to emerge]	ï Student consider the implication of peers claims

Theme Analysis Matrix			
THEME CATEGORY	YEAR I Grade Two	YEAR II Grade Three	YEAR III Grade Four
KNOWLEDGE	Small-group DDiscussion Focus: ï Knowledge guided by teacher		
LEARNING			Large-group discussion Focus: ï Responsibility of learner ï Making connections between ideas
IDEAS	Whole-class Discussion Focus: ï Thoughts ï Pictures in mind ï People may disagree with ideas	Small-group Discussion Focus: ï Pictures in mind ï Explanation of events ï Can be a limiting factor	Word-processed Document Focus: ï Represent thoughts ï Can be temporary explanations ï Can be represented in multiple ways ï Can be linked to other ideas

NATURE OF SCIENCE		Word-processed Document Focus: ï Way of testing thinking	Small-group Discussion Focus: ï More than one way to think about science ï A way of thinking about your thinking
CONCEPTUAL MODELS	Small-group Discussion Focus: ï More than one kind of model ï Models can stand for thoughts		Small-group Discussion Focus: ï Stand for your thinking ï Science is about testing models and changing models

Figure 1 : Theme Analysis Matrix for Jayne

Comparison of Conception Matrix Ideas Theme		
Year I Grade Two	Year II Grade Three	Year III Grade Four
ï A thought that may or may not be performed	ï Thoughts in your head ï Pictures in mind	ï Thoughts in your mind ï Represented thoughts stand for thoughts in mind
ï People may not agree with all your ideas		
	ï Are neither right or wrong ï Some ideas can be better explanation than others	ï Are neither right or wrong ï Can be good explanation of events ï Need to change if not good explanation
	ï Use ideas in mind to think about other ideas	ï Use ideas to think about other ideas
	ï Perhaps some ideas interfere with other ideas	ï In a given situation, can either help or hinder a persons perspective
	ï Begins to question nature of internal vs external representation of ideas [inferred]	ï Can be represented in multiple ways ï Distinguishes between thoughts and representations of thoughts
		ï Can change over time

		ï May be linked to other ideas ï Capable of being applied to new situations
		ï At times thoughts are difficult to articulate ï Thoughts that can be represented are intelligible ï Thoughts that cannot be represented to self [internally represented] are not useful

Figure 2 : Comparison of Conceptions Analysis Matrix for Jayne

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