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ABSTRACT

The intent of this paper is to open for consideration the relationship between metacognition and the promotion of conceptual change within the classroom. This goal is achieved through a brief description of present research by the authors, drawing from the existing literature a summary of what is meant by conceptual change learning, defining the term metacognition and describing the facets included in the definition, a description of the characteristics of a specific learning environment in which metacognition and conceptual change learning occur, and a discussion of the rationale for promoting metacognitive activities within the science classroom. This paper draws on data gathered from three interrelated case studies (M. G. Hennessey, 1991; M. E. Beeth, 1993; and Hennessey, in progress) of students in elementary science at a small midwestern parochial school and provides accounts of students' reflective thinking about science content, students' comments about the relative status of conceptions, and the levels of metacognition that are possible within a classroom setting. Contains 40 references. (DDR)

STUDENTS' REFLECTIVE THOUGHTS ABOUT SCIENCE CONTENT:

A RELATIONSHIP TO CONCEPTUAL CHANGE LEARNING

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Introduction

Research in science education has begun to elucidate some fundamental understanding of the adaptive role of the learner in building internal representations of new experiences in relation to past experiences. As a result, a proliferation of studies have emerged which can be synthesized to form three closely related theoretical perspectives describing the dynamic role of the learner in developing his or her conceptual knowledge. The first theoretical perspective deals with the importance of understanding the nature of students' conceptualizations of phenomena in order to teach fruitfully (Helm & Novak, 1983; Driver, Guesene, & Tiberghien, 1985; Osborne & Freyberg, 1985; Novak, 1987; West & Pines, 1985; Pfundt & Duit; 1991; and Duit, Goldberg, & Neiddar, 1992). The second theoretical perspective is the power of an underlying constructivist epistemology (or at least a constructivist pedagogy), irrespective of the philosophical theory that parented it, to influence students' understanding and learning in science (Magoon, 1977; Hewson, 1980; Resnick, 1983; Strike, 1987; von Glasersfeld, 1989). The third theoretical perspective is a growing recognition that learning involves changing students' conceptions; i.e., conceptual change learning involves **both** building internal conceptions of new experiences in relation to past experiences and modifying internal conceptions which may be at variance with the canonical explanations of natural phenomena (Posner, Strike, Hewson & Gertzog, 1982; Hewson, 1981, 1982; Strike & Posner, 1985; Thorley, 1990; Strike & Posner, 1992). Over the past decade, outcomes to the research conducted from these three theoretical perspectives have been closely inter-woven to provide a powerful means of understanding and interpreting the nature of students' learning in science.

A new theoretical perspective, the significant role metacognition plays in illuminating the nature of students' internal representations in science domains, is gaining in recognition (White, 1986; Baird, 1986; White & Gunstone, 1989; Hewson & Thorley, 1989; Thorley, 1990; Baird, Fensham, Gunstone & White, 1991; Gunstone, 1991; Hennessey, 1991b, 1993; Beeth, 1993). Despite the rising interest in the role of matacognition, no consensus has emerged as to the nature of metacognition in facilitating / promoting conceptual knowledge development within the science classroom. It is our intent, within the structure of this paper, to open up for consideration the nature of this relationship and to examine the implications this has for classroom practice. Our analysis of the relationship will be approached in several ways. First, in order to provide a background against which to contextualize the focus of this paper we will provide a brief description of our present research. An in depth discussion of our research can be found elsewhere (Hennessey, 1991; Beeth, 1993). Second, we will draw from the existing literature a summary of what we mean by conceptual change learning. The model of conceptual change developed by Posner, Strike, Hewson and Gertzog (1982) and expanded by Hewson (1981, 1982) has had a substantial impact on our thinking and subsequent research. Third, we will define the term metacognition as used in our investigations, describing what facets are included in the term. Examples of classroom discourse from our studies will provide evidence to support: (a) our central claim about the substantial diversity of students' metacognitive capabilities, and (b) the notion that individual elements of the learners' metacognitive reflections can be categorized as status related (Thorley, 1990; Hennessey, 1991) or indicative of the various components of their conceptual ecologies (Beeth, 1993). Fourth, we will briefly describe the characteristics of a specific learning environment in which metacognition and conceptual change learning takes place. A fuller description illuminating the essential role of the learners, the teacher, and the instructional activities in facilitating the development of students' conceptual knowledge can be found elsewhere (Beeth, 1993b). Lastly, we will discuss why we think it is imperative to explicitly promote metacognitive activities within the science classroom in order to create an intellectual environment in which the learners willingly engage in the type of critical reflection and discussion that are necessary to promote evaluation of their own conceptions.

The Studies

A great deal of research in science education has been devoted to the study of identifying the conceptions which students hold and quantifying to what extent these conceptions change as a result of various types of instruction. The focus of our current research is not on identifying or quantifying students conceptions per se, but rather on:

* monitoring status changes, viz, the lowering of status (in terms of intelligibility, plausibility, and fruitfulness) of conceptions which are contradicted by canonical explanations and the raising of status of targeted scientific conceptions (Hennessey, 1991; Hennessey, 1991b, 1993; Hewson & Hewson, 1992; Hewson & Hennessey, 1992;)
* characterizing students' metacognitive statements about their conceptions as reflective of components of their conceptual ecologies, and describing how components of the conceptual ecology promotes or inhibits conceptual knowledge development (Beeth, 1993),
* characterizing the nature of students' metacognitive statements and evaluating the impact explicit promotion of metacognition has on conceptual change learning. (Hennessey, in progress), and
* characterizing a learning environment in which the students' current conceptions, the status of their conceptions, and the reasoning used to support their constructs are the central focus of instruction (Beeth, 1993).

In this paper, it is our intent to draw on the data gathered from interrelated case studies of three cohorts of students in elementary science in order to substantiate our claim about the qualitative differences in metacognitive capabilities that are possible within the science classroom; and to explore the nature of the relationship, if any, between metacognition and conceptual change learning. The first study (Hennessey, 1991) demonstrated the effective use of the technical language of the conceptual change model of Posner, *et al.* (1982) to provide a means for students to step back from their ideas and comment explicitly about the status of their current ideas. The second study (Beeth, 1993) describes: (1) the manner in which students' metacognitive statements reflect components of their conceptual ecologies, and (2) the characteristics of a learning environment in which students ideas are the focus of instruction. The third study (Hennessey, in progress) is a three year longitudinal project designed to: (1) explicitly enhance metacognition in order to have the students consider the implications of their reflected thoughts when applied to science topics under consideration, and (2) describe the impact this type of instruction has on the formation of students' ideas. Project META (Metacognitive Enhancing Teaching Activities) attempts to follow the classroom interactions and the development of physical science concepts of specific groups of students (grades 1-6) across three academic years. The project is in its second year of data collection.

Design and Methodology

Although the main focus of the three studies mentioned above is different, each case study originated from a common base of research, had common elements of design, and provided rich detailed accounts of: (1) students' reflective thinking about the topics under consideration (science content), (2) students' comments about the relative status of their own or others conceptions (status), and (3) the levels of metacognition that are possible within a classroom setting. Detailed descriptions, either of the tasks employed to elicit students ideas about content and the analysis used to determine evidence that students can use the technical language of the CCM with meaning are discussed in depth elsewhere (Hennessey, 1991; Beeth, 1993).

The Research Site

All three studies were conducted at the same educational site - a small midwestern, elementary, parochial school with one section per grade level. The students at the research site were ethnically homogeneous, came from families of middle to upper-middle socioeconomic status, and the various cohorts of students had essentially remained intact over the period of their academic education. The sex distribution and number of students participating in each studied varied (See Appendix A, Table A-1).

The academic instruction at this school was departmentalized, that is, the faculty specialized in specific content areas (reading and language arts, math, science, social studies, music or art). All science classes (grades 1-6) were conducted in a laboratory setting by the same science teacher. The science teacher has a strong background in both science and science education (Doctorate in Philosophy), and is currently involved in action research within her classroom. The students weekly schedule with the science teacher included three instructional periods (i.e. 45 min) of science instruction, 1 period of health science instruction, and 1 period computer science instruction.

<u>Content</u>

The science content selected for the three studies was physical sciences. Content specific units were designed to explicitly stimulate classroom interactions that focused on the students' conceptions of concepts considered central to the topics under investigation. A list of content specific units utilized in each study can be found in Appendix A (See Table A-2). A brief description of two units of force and motion, developed for grades 5 and 6 respectively, is given below.

The first unit centered around the use of a circus of 23 demonstrations of objects in motion. The circus was first introduced as demonstrations but remained constantly available throughout the unit for the students to refer to as they attempted to build their understanding of force and motion. The distinction between natural and non-natural motion, as outlined in the Operation Physics program (Nelson, 1988), was used to guide the class discussions on classification of motion activities. Likewise, a discussion between directly and indirectly revealed forces and their relationship to accelerated and non-accelerated motion, was used to guide the discussion of forces and their role in different motion activities. A second unit was developed as a follow-up unit for grade 6 students who had previously worked with force and motion. The unit centered around the same demonstrations of objects in motion. The class discussions focused on the distinction between (1) constant velocity (unaccelerated motion) and changing velocity (accelerated motion), and (2) the effects of balanced and unbalanced forces (unbalanced forces produce acceleration rather than velocity; i.e., they change velocity as opposed to maintaining it). Additional discussions focused on the possibility of an object moving even if the forces acting on it were balanced. In addition, several classroom activities and interactions were employed to augment each unit. Each interaction or activity was selected by the teacher in a pedagogically sound and informed way in order to address: (1) salient issues that surfaced in students' conceptions of the science content, (2) critical distinctions in science content considered necessary for understanding, and (3) ways in which novices could learn the science content at a conceptual level. The two units on force and motion described above and the instructional activities and interactions that accompany these units are representative of the all content specific units developed to guide instruction in this classroom.

Data Gathering Procedures

The data gathering techniques in each study were extensive and conducted on a regular basis. Student responded to the various tasks in both verbal and written form using procedures that were not intrusive to normal classroom practice. Over a period of time the students in grades 1-6 had become familiar with the process of depicting their ideas on posters, explaining their ideas using physical models, and engaging in small group and whole group discussions to express their ideas and discuss some reasons for why they believed their ideas to be the case. The older students (grades 3-6) had developed sufficient skill and familiarity with word processing and speaking (by using audio recordings/video recordings) to capture their thoughts about the issues being discussed. Although the data gathering was extensive, collected from multiple sources only a small portions of the available data is presented in this paper.

The Technical Language of the CCM

Each study can be described as consisting of two conceptually distinct phases. During Phase I, the students in grades 4, 5, 6 learned the technical language of the conceptual change model (i.e. intelligible, plausible, fruitful) by establishing a consensus about the meaning of each term. They accomplished this through a variety of activities involving small group work to identify initial understandings, whole-class discussions of the contributions of the various groups, and building a consensus about a set of descriptors that, for them, best exemplified the meaning of each of the technical terms. A set of descriptors from different grades can be found in Appendix A (See Tables A-3 through A-4).

Application exercises followed to determine whether the students: (1) had developed the concepts of intelligibility, plausibility, and fruitfulness, (2) could sufficiently differentiate between the technical terms on a minimal level, and (3) could apply the technical terms of the CCM to their own conceptions of the topic under investigation. One application exercise taken from Beeth's (1993) study and repeated in Hennessey's Project META is described by way of illustration. This exercise took place after the students in grades 5 and 6 had generated an initial set of descriptors for the terms intelligible and plausible. The students were asked to read various written extracts describing the term intelligible (the process was later repeated using the terms plausible and fruitful). The extracts were taken from several sources, such as professional literature, a doctoral dissertation, a former 6th grade class, and the students' own writings. The authors of the extract were not identified, and each extract was coded as example 1 through example 14. The students were asked to comment on (1) whether the extracts were intelligible (later plausible, fruitful) to them, and (2) the reasons why they considered the extract to be intelligible or, in some cases, unintelligible.

The purpose of this activity was twofold: (1) to confront students with ideas other than their own, and (2) to stimulate a discussion about the perceived strengths and weaknesses of each extract. During this exercise the majority of the students were able to:

* apply their own constructed definitions for the terms intelligible (plausible, fruitful) to the various extracts in order to discuss the intelligibility, (plausibility, fruitfulness) of their ideas about the meaning of the texts;
* differentiate between intelligible and unintelligible passages of text, stating why they considered some words, phrases or whole extracts to be unintelligible;

* comment on the quality of the context of several extracts, such as extracts which seemed, in their opinion to be: (1) a weak or incomplete definition for the term intelligible (e.g., a group of 5th grade students selected their own, unidentified writing as being an incomplete definition), (2) easier to understand (e.g., a group of 5th grade and several 6th grade groups identified the former 6th grade extract as easier to understand), and (3) extracts which were too difficult to generate any ideas for discussion purposes - the extract from the doctoral dissertation was identified by several groups as being "almost totally unintelligible;"
* consider the necessity of strengthening / revising their definition for each of the technical terms.

It is important to emphasize that the students arrived at a final set of descriptors by a process of consensus - it was not a list predetermined by the teacher or researcher and imposed on the class. This process provided confidence to the teacher and researcher that the students knew what they were talking about when they used the technical language of the CCM to determine the status of their own conceptions.

During Phase II the students in grades 4-6 focused on applying the technical language of the CCM to their conceptions of science content in order to determine the status of their conceptions. One's confidence in the outcomes of the students' analysis of the status of their conceptions is, of course, dependent on the evidence they provided, prior to or during the data collection, about the meaning they gave to the technical terminology. Status determination is a more complex task when students do not formally use the technical language. Status determination of non-technical discourse (Hewson & Hewson, 1992) can be derived by employing a status determining framework developed by Thorley (1990).

The two phases described above were not strictly adhered to for the students in grades 1-3. However, the younger students did: (1) discuss and explain their ideas about the topics under consideration, and (2) focus on the distinction between understanding someone else's ideas and accepting or considering those ideas to be 'true.' Application exercises included discussions on: (1) how the students knew they understood (or did not understand) an idea that was not necessarily the same as their own, and (2) why they found (or did not find) an idea to be attractive.

Conceptual Change Learning

To date, there is no consensus within the research community about how best to describe the process of conceptual change. As such, the discussion of conceptual change centers around a number of issues that are germane to teaching and learning, viz, How can we best 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, such as weak knowledge restructuring / strong knowledge restructuring (Carey, 1985), principle or belief changes (Gunstone & White, 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);
* the relative status a learner gives to a conception (Hewson, 1981, Hewson & Thorley, 1989; Thorley, 1990; Hewson & Hewson, 1991; Hennessey, 1991; Hewson & Hennessey, 1991)

Even if some sort of consensus is not reached within the research community, at least our differing views can be interpreted in the light of understanding each others positions on the above issues. Thus, the intent here is not to say how these important issues are described in the literature, for they are used very differently by different authors in different contexts. Rather, an attempt will be made to clarify how they are used in our studies.

That Which is Changing: Conceptions

In our work "ideas" "concepts," "propositions," and "theories" will be assumed to by analogous to "conceptions." We recognize the important distinctions between these terms, but have chosen to side-step a fuller explanation to focus on describing our position on 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 and inversely proportional to the mass of the object), or a theory (general / special theory of relativity) is not germane to our present research. Our current thinking about the term "conception" is similar to that already expressed in the literature (Thorley, 1990). Thorley describes conceptions as:

> ...internal qualities of the mind which structure experiences. They are not "out there" in teacher talk, books, or laboratories, and are certainly not a currency of exchange between teachers and students (p. 75).

A little later he continues:

> ..."conceptions" are only communicated between teacher and learner indirectly, through the medium of internal and external representations (p. 77).

In addition to the conception/representation distinction, Thorley presents a fuller theoretical explanation of the distinction between internal and external representations. For Thorley, representations are what is experienced. External representations are that which is "perceived" by the intended receiver; such as "student talk", "teacher talk," "book talk," or "scientific community talk." Conceptions are what gives the "out there" experiences meaning. Thorely has further noted that when a person has a conception to give the external representation meaning, he / she will be able to construct an internal representation of the "out there" experiences. Conversely, if a person does not have a conception to give the external representation meaning, he / she will be unable to construct an internal representation of the experience; thus rendering the experience unintelligible. In this paper we will adhere to the distinction between "conception" and "representation" as defined by Thorley.

A Change in Knowledge States: Conceptual Change

One of the strongest threads running through the literature on conceptual change learning is the notion that not all changes in knowledge states can be considered the same. Most researchers working in the area of conceptual change concur that changes in which a person displays evidence of understanding a new science concept or acquires a new science skill is conceptually different from a change in which a person displays evidence of a major shift in belief about a key principle or an interpretation of a phenomena. In the process of trying to delineate these unique differences, researchers have focused their attention on defining what counts as a change in a conception. In doing so, however, there is no sense in which one view of conceptual change (i.e., weak / strong knowledge restructuring, accommodation / assimilation, principle / belief change, conceptual capture / conceptual exchange) has emerged over any other as a more powerful way of characterizing the notion of change in a learner's knowledge state. As a result of this situation, researchers must define, what seems to them, to be considered a shift in a student's thinking.

Our position on the notion of a change in a person's conceptions is similar to that expressed by Posner *et al.* (1982) and Hewson (1981, 1982). Both the accommodation / assimilation and conceptual capture / conceptual exchange distinctions seem to us to be an appropriate characterization of the types of change considered necessary for conceptual learning to occur. (In this paper, in order to avoid confusion with the Piagetian use of the terms "accommodation" and "assimilation" we will employ the terms "conceptual capture" and "conceptual exchange.") The distinction between conceptual capture and conceptual exchange is thoroughly defined in the literature (Posner, et *al.*, 1982; Hewson, 1981, 1982; Strike & Posner, 1985, 1992; Thorley, 1990); thus, it will not be repeated here.

The notion of teaching for conceptual capture as well as conceptual exchange seems to us, as educators as well as researchers, to be a powerful mechanisms for facilitating the process of conceptual knowledge development. Much of what students do during the learning process is to understand new ideas in light of what they already know: viz., by making connections between what they know and that which is new. This is not a problem for learners when their present views can be reconciled with what they are learning; the result is an elaboration or enrichment of their current conceptions. It is only when reconciliation does not occur that both learner and teacher need to invest time in considering how to best facilitate the process of conceptual exchange. It is our opinion, that perhaps a more powerful approach to facilitating conceptual knowledge development is to seek ways to create learning environments in which both the teacher and students explicitly address learning as a process of conceptual capture as well as conceptual exchange.

Metacognition

Before turning to the task of describing the levels of students' metacognitive capabilities that can exist within a classroom setting, it is necessary to address the issue of how the term metacognition is used. White (1989, p. 504) accurately pointed out that "authors are free to give whatever meaning they choose to a word." If, however, the reader is not aware of the author's meaning, this practice will likely lead to misunderstanding or confusion. In order to clarify, for the reader, our present understanding of the term metacognition we will: (1) briefly cite several different ways in which the term has been interpreted in the literature; and (2) describe what facets are to be included or excluded by the term as used in our studies.

The term metacognition was first introduced by Flavell (1976). He states:

> 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).

Flavell's definition made explicit the multidimensional character of metacognition: an awareness of one's own thinking, active monitoring of one's cognitive processes, and an attempt to regulate these processes in relationship to further learning. Furthermore, Brown (1978) has defined metacognition as "knowing about knowing." She summarized metacognitive activities under two categories: (1) activities that are concerned with conscious reflection on one's cognitive abilities; and (2) activities that are concerned with self-regulatory mechanisms during on-going attempts to learn or solve problems. Brown's two categories differentiate between (1) what people know about their thinking processes and (2) the application of a set of heuristic as an effective device for helping people organize their methods of attack on problems in general. Kuhn, Amsel, & O'Laughlin (1988) have noted that the term metacognition is often employed in such a board and variable ways as to risk losing its explanatory value. In their opinion, the key aspect of metacognitive operations entails "conscious awareness:"

> ...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).

Thus, for Kuhn, *et al.* the heart of being metacognitive is the ability to represent theories as an object of cognition. Thorley (1990) suggested a similar distinction between "metaconceptual" and metacognitive" components of metacognition. Metaconceptual reflections are described in the Kuhnian, *et al.* sense: reflections on conceptions, rather than unreflected application of them to the description or explanation or phenomena. Metacognitive reflections apply to reflections on, or reference to thinking or learning processes that are not related to particular conceptions. Baird, Fensham, Gunstone & White (1991) 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 touches on specific learning strategies: processing, evaluating the processing, and deciding. Lastly, White (1989) 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 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).

A cursory review of the literature concerning the ontogenesis of metacognition reveals a lack consensus on the meaning of the term in general. Likewise, a review of the literature concerning the body of research aimed directly at the metacognitive activities of either children or adults reveals most studies of metacognition are studies of cognition about how to learn and remember or studies of the cognition involved in choosing and monitoring strategies to solve problems.

The focus of our current work is one of monitoring young children's ability to reflect on their own or other's conceptions as they learn science content. Such reflections are thus in the metacognitive realm. At this point, it is worthwhile to make explicit several aspects of what we mean by the term metacognition. First, we acknowledge the multidimensional character of metacognition as expressed by the above authors. Second, our current thinking about the most significant aspects of metacognition, is similar to that already expressed in the literature by Kuhn *et al.* (1989). Metacognition consists of an inner awareness or ability to reflect on what one knows and how one knows (i.e., thinking explicitly <u>about</u> the ideas or conceptions one holds rather than merely thinking <u>with</u> those conceptions). Third, included in this metacognitive process of thinking about one's conceptions is the ability to:

* consider the basis for one's belief in a specific conception,
* temporarily bracket, or set aside, one's conceptions in order to assess competing conceptions,
* consider the relationship between one's conceptions and any evidence that might or might not support those conceptions, and
* evaluate the consistency and generalizability inherent in one's conceptions.

Excluded from our definition of metacognition is the ability to (1) execute a sequence of strategies, (2) employ a set of heuristic that lead to success on a task, and (3) explicitly self-regulate one's behavior in the midst of performing complex tasks. Specific examples of what is excluded from our characterization of the term metacognition are:

* learning strategies: the ability to make inferences, check for understanding, summarize or paraphrase text, recognize contradictions or ambiguities in text, reinspect text, generalize, resolve comprehension

difficulties, develop or assess a set of learning goals for an activity;

* 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
* 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.

In our opinion, teaching students a set of learning strategies, heuristic for solving problems, or recommending self-regulating behaviors that have the potential to lead to success on a given task, however desirable these competencies may be, does not guarantee awareness of one's thoughts, nor the ability to contemplate the rational arguments used to support one's knowledge claims about the topic under consideration. What is involved in each aspect of these competencies is the observable feature of successful or desirable performance. Successful performance per se entails reflection on selecting correct strategies (i.e., knowing what to choose so to speak, in terms of solution attainment and efficiency). This does not mean, however, that we are of the opinion that learning strategies, or self-regulating tasks cannot occur within the metacognitive realm. To do so 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. It entails not just selection of the correct strategies to employ, but entails 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.*: the ability to think about the significance of a specific strategy as opposed to merely unreflected execution of a set of strategies.

In summary, we consider a person who displays evidence of metacognitive ability as standing in direct contrast to an individual who uses his/her conceptions as a means of organizing experiences and thinking about the world, but does not think about the conceptions themselves; nor does the individual contemplate the rational arguments used to support his/her knowledge claims.

Levels of Metacognitive Reflection

Characterizing metacognition as thinking about thinking (Flavell, 1976), as knowing about knowing (Brown, 1978), or as thinking explicitly about the ideas or conceptions one holds rather than thinking with those conceptions (Kuhn, *et al.*, 1988) is intriguing, but lacks in both clarity and detail. In our efforts at both explicitly promoting metacognition within the science classroom and characterizing the nature of students metacognitive reflections, we have noticed a significant difference in the type of metacognitive reflections produced by the students in our studies. The differences in the types of metacognitive reflections range from what we would consider as a minimal level of awareness of one's own conceptions through various levels of more sophisticated capabilities. In order to better characterize the nature of these differences we have established a framework for analyzing metacognitive statements in the form of a system of categories. These categories are not hierarchial in nature, although they do reflect an increasing sophistication in the student's metacognitive capabilities.

The following categories were employed to classify different types of metaconceptual discourse. Samples of student discourse, which were rich in metaconceptual references, are provided for purpose of clarification. Efforts were made to select samples of students' thinking or reasoning which reflected the canonical as well as the non-canonical view of science.

Reflections which explicitly refer to one's own personal constructs, or knowledge claims.

Included in this level are metacognitive statements in which a student explicitly refers to his/her own conception or a peer's conception. We consider the ability to explicitly think about the ideas or conceptions one holds (we assume there be some external representation of those conceptions) a minimal requirement for students' discourse to be considered metaconceptual in nature. Likewise, explicit reference to a peer's, teacher's, or the scientific communities' representation of a conception is an extension of this ability.

The following extract came from a transcript of a grade six small-group discussion. Prior to the discussion, the students were given a questionnaire that asked them to (1) select a force explanation from a list of options, (questionnaire showed six pictures representing possible force combinations acting on a book as it rested on a table), (2) give reasons for their choice, and (3) comment on the intelligibility, plausibility, and fruitfulness of their choices (See Appendix A, Fig 1-A). Small group discussions were conducted as a follow-up to the questionnaire.

Andy: I think there is only one force acting on the book as it rests on the table and that force is gravity. The table cannot cause a force, it [the table] is just in the way (Hennessey, 1991).

Andy's comments shows that he is capable of describing his ideas about the force or forces acting on a book as it rests on a table. In doing so, Andy provides valuable information about his personal beliefs that "the table cannot cause a force, it is just in the way."

The following is an extract from a grade one whole-class discussion transcript. The students were asked to predict, observe, and explain the floating and sinking of a variety of common objects.

Jenna: Some things just float and some things just sink and I think they're just made to do that (Project META, year 2, grade 1).

Jenna's comments shows that she is capable of explicitly referring to her personal knowledge claims--objects sink because "they're just made to do that" (i.e., it is within their nature to do so).

The following extract of a grade six small-group discussion transcript, shows what we consider to be an example of a student explicitly referring to a peer's conception. The small-group discussion focused on the possibility of an object moving, even if the forces acting on it were 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 year 1, grade 6).

Katie provides evidence of a student's ability to refer to a peer's thoughts ("I know what you are saying...you think that..."). She seems to 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 ideas about the type of forces acting on an object 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, viz., that constant velocity is possible with balanced forces.

The last example given in this section came from an extract of a grade two whole-class discussion transcript. The focus of the discussion was on the content of students' ideas about what they think happens to a solid as it dissolves in a liquid. In order to stimulate a rich, full discussion the students were requested to perform a simple dissolve task. The teacher was careful not to introduce the term "dissolve" at this time. The students were given two jars containing the same amount of water and two packets of table sugar. They were requested to empty 1 packet of sugar into each jar, leave one jar uncovered, and to place a lid on the second jar. The contents of the open jar was stirred with a spoon; the contents of the closed jar was swirled. The students were asked to explain their ideas about what had happened to the sugar in both jars.

Eric: [Referring to the jar with the lid] The sugar couldn't have just disappeared out of the jar it has to still be in the water someplace because I put a top on it [the jar] and I know it [the sugar] can't get out (Project META, year 1, grade 2).

Eric reveals his ideas about the location of the sugar (..couldn't have just disappear out of the jar it has to still be in the water...I know the sugar can't get out).

Due to the highly interactive atmosphere and conceptual orientation of the classes at all grade levels, it was relatively easy to obtain examples of students identifying their conceptions such as the ones presented here.

Reflections which explicitly refer to the reasoning behind one's constructs or knowledge claims.

The ability to examine <u>why</u> one is attracted to specific knowledge claims, ideas, or concepts goes beyond the recognition of one's personal knowledge claims. Metacognitive statements that explicitly refer to the reasoning behind the learner's constructs are included in this category. The following extract came from a grade one unit 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 the teacher conducted a demonstration. She placed a transparent container filled with water on the overhead projector and asked the students to predict what they thought would happen when various objects were placed in the water. The segment of classroom discourse printed below is taken from this demonstration. 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 the opportunity to handle the stones.

Briana: <t: Would anyone like to predict what they think will happen to these stones. Yes, Briana.> I think the both stones will sink because I know stones sink (pause). I've seen lots of stones sink and every time I throw a rock into the water (pause) like it always sinks (pause) yeah it always does. (long pause) <t: You look like you want to say something else.> (Pause) Yeah the water can't hold up rocks like it holds up boats and I know they'll [stones] sink <Peer: Yeah> <t: You sound so sure, let me try another object.> No you gotta throw it in, you gotta test my idea first. [Small stone is placed in the tank--it sinks] <peers: cheers.> See, I told you I knew it would sink. [Teacher places larger rock down and picks up another object.] No you've gotta test the big one too because if the little one sunk the big one's gotta sunk (sic). [Larger stone is placed in the tank--it floats.] [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. [Students gather around the overhead, excited about what they saw. The discussion continues.] (Project META, year 1, grade 1).

In this case, Briana clearly refers to her ideas about what will happen to the stone ("...both [of the] stones will sink...I know they'll sink"). She draws on her experiences with casting stones in water to support the reasoning behind her ideas ("...I've seen lots of rocks sink...every time I throw a rock into the water...[it] always sinks"). When confronted with a discrepant event, Briana indicates her reasoning as to why she thinks the event should not have happened ("...That's not right...it just doesn't go with my mind").

The following example came from a grade six written response to the following statement: "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: 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, year 2, grade 6).

Jill's response to the statement above demonstrates her ability to go beyond mere recognition of her personal constructs to comment on <u>why</u> she is attracted to her knowledge claims. As she readily acknowledges, her ideas have changed during the course of the year. She is able to provide a contrast between her previous and current 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 tow balanced forces instead of just gravity..."). She does not directly identify the second force acting on the book. Jill reveals two strands of reasoning used to guide her current conceptions: (1) reasoning about the relationship between "balanced forces" and "constant velocity," ("...balanced forces are needed to produce constant velocity!...") and (2) reasoning as to 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.").

There are two conclusions that can be drawn from the forgoing discourse: (1) that the students in question were capable of going beyond mere recognition of their own personal constructs to comment on why they were attracted to their knowledge claims, and (2) their ability to articulate the reasoning behind their knowledge claims provides added insights in to their understanding of the topic in question (i.e., insights that would not, otherwise, be available to their teacher).

Reflections that explicitly consider the implications or limitations inherent in one's constructs or knowledge claims.

Included is this category are metacognitive statements which are: (1) indicative of a learner's ability to explicitly consider the potential strengths or weaknesses of his / her conceptions, or (2) show evidence that the learner is aware of the possible limitations of his / her conceptions. The ability to explicitly consider one's conceptions as having the potential to be effective or ineffective, as the case may be, or 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 capabilities.

The following extract came from a transcript of a grade six small-group discussion. The small-group discussion focused on the individual student's ideas 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).

In the above case Luke provided evidence of his ability to articulate his conceptions of molecular motion and to draw on his past experiences as evidence to support his conceptions. Luke provides further evidence that he was aware of a view of molecular motion that was in direct competition to his own ("...the molecules are suppose to be in constant motion..."), explicitly consider 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 present view ("...If I choose not to believe...my whole theory of heat doesn't work...").

<u>More Sophisticated Levels of Metacognitive Reflections</u>

The following levels contain extracts that are characteristic of the diversity and sophistication exhibited in student's metacognitive statements. The statements provide evidence to substantiate our claim that their is a qualitative difference in students' metacognitive capabilities.

Reflections that explicitly refer to one's own thinking or learning process.

The excerpts of metacognitive discourse assigned to this category are clearly indicative of these students' abilities to reflect on their thinking process as an objects of cognition. The following extract came from a grade four transcript of a whole-class discussion. The students were asked to explain how they determined the plausibility of an idea. The teacher 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 all 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 their thoughts into words? Ok...

Several students responded to the above statement. The following two extracts are representative of the quality of responses given by members of the class.

Kelly: Well first, I (pause) first I listen to what the person is saying and then I think about it. And then I look at my experiences because my ideas are sort of mixed in with my experiences. And then I try to see if (pause) that (pause) if they belong with my ideas. But I sorta use my ideas to think about what the person is saying. (pause) Yeah (pause) I use my ideas to decide if the other idea is plausible (pause). Just because I understand it doesn't mean it's plausible. It kinda has to go with my experiences. I sorta think about my ideas and my experiences (pause) because it has to go with my experiences. I doesn't hafta match perfectly but it does hafta kinda go with my experiences or I just don't think it's a plausible idea.

Teacher: Ok. Can I try to repeat back what I think you said. Tell me if I misunderstood you. Ok. I think you said: here is my idea and I'm using my idea to look at somebody's else's idea. And I want to find out whether the other person's idea is plausible. You don't know whether their idea is plausible to you. And what I think I hear you say is: I have lots of experiences. Can you tell me more about the experiences?

Kelly: Yeah. I sort of take the idea and check with my experiences.

Teacher: What happens if the idea fits with your experiences?

Kelly: Then it becomes plausible and when its plausible it usually is already part of my idea. From the beginning I usually know if it plausible to me because of my experiences (pause) after I look it over.

Teacher: What happens if it doesn't go with your experiences? What do you do with the other person's ideas?

Kelly: I sort of like (pause) well I look it over and I put it away if it doesn't go with my experiences. But if they have a good explanation I think about it some more because I can't experience everything but if they don't I throw it away.

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 ideas 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 ideas that isn't plausible to you now can change to a plausible ideas 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.

Both Kelly and Eamon demonstrate very impressive metaconceptual capabilities by explicitly commenting on their thinking processes. In the first case, Kelly's unsolicited use of the term plausibility adds considerably to our confidence that she understands the nature of the task ("...I use my ideas to decide if the other idea [someone else's idea] is plausible. Just because I understand it [someone else's idea] doesn't mean its plausible..."). Kelly articulates her process of thinking about another's idea ("...I listen...then think about it [the idea]...I look at my experiences...I use my ideas to think about what the person is saying...It [the idea in question] kinda has to go with my experiences...It doesn't have to match perfectly..."). At the teacher's request Kelly elaborates on the importance of her experiences ("...I sorta of take the idea and check with my experiences...when it's plausible it usually is already part of my idea...I put it away if it [the idea in question] doesn't go with my experiences...but if they [the person who's idea is being considered] have a good explanation I think about it some more because I can't experience everything...").

In the second case, Eamon articulates his thinking 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..."). Eamon refers 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 he was quick to respond that he was using an analogy. He equated his use of analogy with 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 to making connections between what he knows and the 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 questioned about the possibility of an idea changing from one that is not plausible to him to an idea that is plausible, Eamon elaborated on his ideas about how this process occurs. He indicated that a change in plausibility does 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...").

Both extracts reveal impressive qualitative statements about the students' thinking process. One cannot doubt that Kelly and Eamon display highly sophisticated metacognitive capabilities that go far beyond a propositional statement of understanding or belief.

Reflections that explicitly refer to the status of one's conceptions.

Included in this level are metacognitive statements which demonstrate the ability to explicitly comment on the status of one's conceptions. Evidence of status is reflected in a person's ability to: (1) explicitly reflect on his or her conceptions as objects of cognition, (2) bracket knowledge or beliefs temporarily in order to talk about the intelligibility, plausibility, and fruitfulness of that conception, and (3) provide, prior to or during the data collection, some evidence of understanding of the individual terms (I, P, F).

The following extract came from a transcript of grade four whole-class discussion. Prior to the discussion the students were shown a series of overhead visuals that depicted the canonical explanation about the arrangement and motion of atoms during state 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 any way which made sense to them. The teacher prefaced the 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. Lets 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 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]...[several students respond, the teacher calls on Kathryn] <t: 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.

At first Kathryn states that the visuals are intelligible, plausible, and fruitful for her without providing any explanation as to what the terms mean to her. She compares the concepts represented by the visuals with her own concepts and provides direct evidence for the status of her ideas about the content represented by the visuals ("...I understand all of them and I believe all of them and I think all of them are useful to my ideas..."). In addition to these comments, Kathryn provides evidence that she understands what is being depicted ("...molecules...vibrate and move away from each other as they change from solids and liquids and gases..). For plausible, she compares her ideas to those represented by the visuals ("...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..."). Thus, Kathryn gives us some insight into her belief about the changing nature of atoms. For fruitful, she provides evidence that the concepts represented by the visuals are, for her, a useful way to describe changes in matter ("...they are useful to my ideas...I can better explain me ideas about the molecules...to the group...").

<u>Reflections that explicitly refer to one's metaphysical beliefs, epistemological commitments or other components of one's conceptual ecology.</u>

Included in this level are metacognitive statements in which a person: (1) explores his or her metaphysical beliefs about what they consider to be true about the real world or qualities of objects, (2) refers to the function of epistemological commitments (i.e., consistency in reasoning and generalizability of that reasoning to other circumstances), (3) explicitly uses analogies, metaphors, real world prototypical exemplars, or conceptual models. Although it remains to be seen if students can comment directly on specific components of their conceptual ecologies, it is reasonable to assume that students can and will provide some indications of their conceptual ecologies.

The following extract came 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.

Mich Q: 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 than'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: were 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 to 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 lets 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.

In this case, Melinda readily acknowledges that the cconceptions represented in the visuals are intelligible but not plausible to her. She provides evidence as to why she finds the concepts lacking in plausibility ("...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..."). For Melinda, her metaphysical beliefs about the nature of atoms [atoms are not living entities] are clear to her and strongly held. She generalizes her misunderstanding [only living things have the capacity to move without the influence of an external forces] about a specific characteristic of living things to apply that understanding to non-living objects. She provides evidence that she is aware of a contrasting position [atoms are in constant motion] and indicates a lack of understanding in the metaphysical beliefs 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 to 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 means to be alive 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 understand the concept that Jack is trying to represent to her ("...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"). The teacher interrupts the conversation to clarify what was said by way of an illustration. Melinda provides evidence that she understands the teacher's illustration but indicates that she needs a mechanistic explanation to help her understand (i.e., an explanation of <u>how</u> molecules could possible move).

Discussion

In this paper we have stated our position on several issues that are important to conceptual change teaching and learning, viz.:

* we described a way of monitoring the status as a means of analyzing learners' conceptions and influencing the course of conceptual change,
* defined the term "conception" as what can be internally represented,
* described our approach to conceptual change learning as including both the processes of conceptual capture and conceptual exchange,
* addressed the issue of how the term metacognition is used in our studies,

enumerating what is to be included and excluded,

* cited several examples of what we consider to be different levels of metacognitive awareness as reflected by the students in our studies

Several conclusions can be drawn from the cases presented in this paper. First, the data has been interpreted to show that the students in question can provide extensive and varied evidence of their metacognitive capabilities. Second, that our data analysis indicates extensive evidence of a qualitative difference in the types of metacognitive statements produced by the students. In order to conduct an analysis of these qualitative differences a framework was devised for categorizing the learners' ability to:

* represent personal constructs or knowledge claims,
* make public the reasoning used to support personal constructs or knowledge claims,
* explicitly consider the implications or limitations inherent in personal knowledge claims,
* refer to personal thinking / learning process,
* determine status (i.e., the intelligibility, plausibility and fruitfulness of on personal ideas about the topic under consideration),
* to use models of their conceptions such as images, analogies, and exemplars and to talk about consistency with other knowledge or past experiences, causal mechanisms, epistemological or metaphysical beliefs.

These multi-level dimensions of metacognition add considerable richness to our present understanding of metacognition and to potential evaluations of the content of classroom discourse. A final conclusion is that our analysis of status, especially when working with students who know and can use the technical language of the CCM, provides insight into the reasoning and justification behind students ideas and components of students' conceptual ecologies.

In order to promote concpetual change learning it is necessary for the students to continually engage in metacognition. Failure on the part of the student to examine their conceptual understanding and the cognitive processes that produce that understanding cannot be expected to result in learning scientific knowledge at a conceptual level. Students are capable of metacognitive reflection if given the right circumstances, it is incumbent upon the teacher to provide an appropriate intellectual environment in which this metacognitive reflection can take place.

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