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ABSTRACT

Project META (Metacognitive Enhancing Teaching Activities) is a 3-year naturalistic case study designed to explicitly enhance the metacognitive capabilities of learners in order to illuminate the nature of metacognitive interactions among elementary students and to describe the impact this type of enhancement has on the formation of students' conceptual knowledge. This study discusses the preliminary findings of the first year's data in which the classroom interaction and development of physical science concepts of six cohorts of students, grades 1-6, were studied. The study examines how metacognition can be promoted in individual science students, the role of classroom discourse in facilitating the development of metacognition, the nature of metacognitive processes, and the role of metacognition in promoting conceptual knowledge development in the elementary science classroom. Selected samples of discourse from six different grade levels illuminated the nature of metacognitive interactions among elementary students. Data analysis indicates that: (1) students can provide extensive and varied evidence of their metacognitive capabilities; (2) students become more capable of being metacognitive over time as evidenced by comparisons of metacognitive discourse taken from second, third, and fourth graders; (3) a qualitative difference in the types of metacognitive statements is produced by the students; and (4) conceptual changes took place in the learners as indicated by the students' statements. Contains 33 references. (MDH)

STUDENTS' IDEAS ABOUT THEIR CONCEPTUALIZATION: THEIR ELICITATION THROUGH INSTRUCTION

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Introduction

Over the past twenty years there have been major efforts in science education research to identify students' ideas about scientific phenomena, both prior to and following formal instruction. Data analysis from various studies have been interpreted by the science education research community to provide insights into the dynamic role of the learner in building internal conceptions of natural phenomena and the implications these conceptions have for subsequent teaching and learning in science.

The research reported on in this paper has been influenced by the results of previous studies of students' conceptions of science content and guided by four theoretical perspectives that have become widely accepted. First, we have accepted 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). Second, we have accepted 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). Third, we have recognized that learning involves changing students' conceptions; namely, 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). Lastly, 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, 1992; Hennessey, 1991b; Beeth, 1993; Hennessey & Beeth, 1993).

The significance of this study is that it moves beyond identifying and quantifying students' conceptions per se, to:

- monitoring status changes, namely, the lowering of status in terms of intelligibility, plausibility and fruitfulness of conceptions that are contradicted by canonical explanations and raising the status of

targeted scientific conceptions (Hennessey, 1991; Hennessey, 1991b; Hewson & Hewson, 1992; Hewson & Hennessey, 1992),

- monitoring and characterizing students' metacognitive statements about their conceptions as reflective of components of their conceptual ecologies (Hennessey & Beeth, 1993), and
- monitoring and characterizing the nature of students' metacognitive statements and evaluating the impact explicit promotion of metacognition has on conceptual change learning (Hennessey & Beeth, 1993).

The significance of investigating status in relation to conceptual change has been addressed by Hewson and Thorley (1989), and Thorley (1990); the relationship between status change and conceptual change has been addresses by Hennessey (1991); and the relationship between changes in individual components of a learner's conceptual ecologies and conceptual change has been addressed by Beeth (1993, 1993b); thus, these issues will not be repeated in this paper. That there might be a significant relationship between metacognition and conceptual change was recognized by White (1986). I agree with White's provisos that "much learning is superficial, being done without deep reflection" and recognize the value of explicitly "promoting metacognition within the classroom," but differ in the way I describe metacognition.

Nature and Purpose of Study

Project META (Metacognitive Enhancing Teaching Activities) is a three-year naturalistic case study designed to explicitly enhance the metacognitive capabilities of learners in order to: (a) illuminate the nature of metacognitive interactions among elementary students, and (b) to describe the impact of this type enhancement has on the formation of students' conceptual knowledge. This study attempts to follow the classroom interaction and the development of physical science concepts of six cohorts of students (grades 1-6) across three academic years. The project is near the end of its second year of data collection.

The ultimate aim of Project META was to illuminate the nature of metacognitive interaction among students, and between teacher and students, which have the potential to make public: (a) the status of individual students' conceptions, (b) the reasoning used to support those conceptions (i.e., the justification, implication and limitation of their reflected thoughts when applied to science content); and (c) the various

components of the students' conceptual ecologies. Reflections of this type are metacognitive in nature and are essential in order to adjust instruction so as to enhance or challenge components of the learners' conceptual ecologies that might influence a change in a conception. The specific questions addressed in this longitudinal study are:

1. In what way can metacognition be promoted in individual students within the science classrooms?
2. What role does classroom discourse play in facilitating the development of metacognition in individual elementary students?
3. What is the nature of metacognitive processes?
4. What is the role of metacognition in facilitating or promoting conceptual knowledge development within the elementary science classroom?

These questions will be considered to have been answered satisfactorily when enough data (in the form of students' verbal or written comments) has been gathered over an extended period of time, to allow for qualitative interpretation by the researcher so as to ensure that the description arrived at and the results are valid for more than just one student. Preliminary findings based on one academic year of data collection are discussed in this paper.

Nature of the Investigation

The investigation comprised a naturalistic case study of learning of physical science topics by students in 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 K-6 education.

A full description of the design and methodology employed in this study is beyond the scope of this paper. In order to contextualize the study, however, several unique features that are pertinent to classroom environment and methodology are highlighted. One feature is context within which the classes were conducted. All science classes (grades 1-6) were conducted in a laboratory setting by the same science teacher (i.e., over a six year period each cohort of students would have had the same science teacher until

matriculation at the end of grade 6). A second feature was that the researcher conducting the study served as the students' regular science teacher. Thus, the research being conducted was not distinct from practice. Implementation of research finding to classroom practice became a mute issue because it occurred simultaneously with and was synonymous with the generation of knowledge and understanding gained from the research. A third feature was the data gathering techniques. Data gathering was extensive and collected from multiple sources. The procedures used were an integral and normal part of established classroom practices: representing and communicating conceptions in terms of illustrations on posters, physical models, the use analogies, or prototypical exemplars; engaging in small group and whole group discussions to communicate representations of their intuitive theories; and familiarity with word processing and speaking (by using audio recordings/video recordings) to capture their thoughts about the issues being discussed. Only a very small portions of the available data is presented in this paper.

Metacognition Defined

The term metacognition has been interpreted several different ways within the literature. A review of the literature concerning the body of research aimed directly at the metacognitive activities of either children or adults reveal 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 term metacognition is often employed in such a broad and variable way that it often loses it explanatory value. Therefore, it becomes imperative, for the purpose of clarification to address the issue of how the term metacognition is used in this study.

My current thinking about the most significant aspect of metacognition is similar to that already articulated in the literature (Kuhn, Amsel, & O'Laughlin, 1988). Metacognition consists of an inner awareness or ability to reflect on what one knows and how one know it (i.e., the heart of being metacognitive is the ability to think about theories as an object of cognition). During the past six years, based my work of promoting and monitoring the metacognitive capabilities of children (ages 6-12) within the science classroom, I have extended my view of metacognition to include the learner's 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,
- consider explicitly the status of one's own conceptions, and
- evaluate the consistency and generalizability inherent in one's conceptions.

Excluded from this view 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 this 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 my 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 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 person who displays evidence of metacognitive ability as standing in direct contrast to an individual who uses his or 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 or her knowledge claims.

Promoting Metacognition to Facilitate Conceptual Change

The question of how to promote metacognition has aspects more pragmatically related to teaching for conceptual change and also aspects more theoretically related to revealing the status of students' conceptions as well as documenting changes in students' conceptual ecologies. To date there is no consensus within the research community about the ways in which metacognition can be best promoted nor about the role metacognition plays in facilitating or promoting conceptual change. At present such a discussion centers around describing specific processes that learner must know, or be aware of, or control. Various researchers working the area of metacognition have produced tentative lists of student behaviors or a sets of strategies to be executed as an effective device for helping learners organize their method of attack on problems in general. The intent here is not to critique the endeavors of different researchers, for what each researcher see as important to the process of metacognition may be closely linked to the context within which each of us works. How one goes about promoting metacognition among secondary students who have been inculcated into the process of schooling for nine, ten, or eleven years may be significantly different from how one goes about promoting metacognition in younger students who have been exposed to the process of schooling for a few years. Another factor to be considered is the years of experience a student has had at being

metacognitive. The question arises: Are the metacognitive capabilities of students who are engaging in metacognition for the first time the same as those students who have had multiple years of experience at being metacognitive? If the answer to this question is no, then the process used for more experienced students, of necessity, needs to be different.

The following are a set of teaching / learning goals developed to facilitate in young students the ability to think about their own conceptions as objects of cognition. The students in this study are encourages to:

- state explicitly their own view about the topic under consideration;
- examine the reasons why they are attracted to their views;
- look for some consistency among their beliefs;
- explore the implication of their views over a wide range of activities while looking for some underlying commonalities;
- consider the implications and limitations of the view they hold or are currently considering and the need for possible revision;
- explore abstract concepts, propositions, or theories by constructing physical representation of their current ideas or by employing analogies, metaphors, real world prototypical exemplars or conceptual models;
- distinguish on a minimal level the difference between the terms intelligible, plausible and fruitful (students in grades 4-6) or distinguish the difference between understanding an idea and accepting that idea to be "true" (students in grades 1-3); and
- explicitly talk about the status of the conceptions they hold or are presently considering.

The set of teaching / learning goals is somewhat hierarchial in nature. It stands to reason that learners needs to become aware of what it is they think about a specific concept or their own knowledge claims before they can begin to consider: (a) the reasoning used to support their conceptions or (b) the implications or limitations inherent in their personal constructs. Other learning goals used in this project to promote metacognition are not hierarchial in nature. For example, the learners' ability to explicitly reveal the status of a conception they are considering does not necessarily precede or antecede the learners' ability

to explicitly use analogies or give real world prototypical examples as a means of representing the conception in question. Likewise, the learners' desire to look for consistency in reasoning or generalizability of that reasoning to other circumstances is not hierarchal in nature.

It is important to keep in mind that the above teaching / learning goals. are not an end in themselves. Rather, they are simply a means to facilitate the creation of an intellectual environment, free from dogmatic evaluation, in which students are encouraged to make public: (a) their epistemological beliefs about how knowledge should be developed, and (b) their metaphysical beliefs about the nature of world. In addition, the goals provide a mechanism for the teacher to make explicit, in a way that is pedagogically sound for young learners, key components in a conceptual learning process (viz., the importance of status, consistency and generalizability). The practice of encouraging students to consider their personal views in the light of new and perhaps conflicting information, and to look for consistency or generalizability in constructing new knowledge has to potential, over time, to empower students to take control of their own cognitive learning process.

Role of classroom Discourse in Promoting Metacognition

In the previous section, a question was posed regarding the metacognitive capabilities of students' who are experienced at being metacognitive versus students' who are engaging in metacognitive activities for the first time. The answer to the posed question may lie in the classroom discourse itself. One plausible explanation is that students who engage in metacognitive discourse become more sophisticated in their metacognitive capabilities. It is not within the design of this study to investigate the proposition that practice at being metacognitive facilitates a deeper level of metacognition. Such a study would be difficult to design and I would not personally feel comfortable relocating any student to a control group. In lieu of a controlled study, perhaps some examples drawn from this study can shed light on the proposition posed above.

Example 1

The following extract came from a transcript of a grade 2 whole-class discussion. The focus of the discussion was students' ideas about the meaning of the word "idea." The comments of one particular student (Jenny) are extracted from the comments of the class as a whole. To conserve space, notations are made in

brackets about large segments of "classroom talk" that have been excluded from the discussion printed below.

[The teacher spent 3 to 5 minutes setting the context for the discussion. Jenny opens the discussion.]

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

Jenny: 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 Jenny what she means by a thought.]

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

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

Teach: [To whole group] You're trying to tell me if I just think of something <s: yeah> that's an idea <several students: Yeah.> or do I have to do it then it's an idea <several students talking at once.>

Jeff: No you don't have to do it, you can keep it in your head.

Teach: You mean it works if I just think of it?

Jenny: Yep! That an idea.

Jeff: You have an idea.

Teach: Hey! That's really neat! But you don't know what my ideas are. Do you?

Stds: No

Jenny: But if you thought about it that's an ideas. (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 thing 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.

Jenny: No. Well listen.

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

Jenny: 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.

Jenny: Two and two are four.

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

Teach: Two and two are five.

Jenny: 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?

Stds: [Several] Yea. [Several] No.

Thea: Yes there is (pause) yes there is.

Jenny: No there isn't

Thea: There is (pause) yeah there is (pause) hum (pause) I got a good example.

Teach: Ok. An example. I love examples. They help me think about things...

Thea: Hum (pause) if (pause) hum (long pause) now I forgot what I was going to say.

Teach: An example.

Jenny: 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 you idea of what you think it is...

[Jenny gives an example involving a balloon that was mistaken 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 Jenny has something to add to the discussion.]

Jenny: ...you want another example?

Teach: Great! I'd love one!

Jenny: 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.

Jenny: 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.

Frank: Then we wouldn't laugh.

Jenny: Then we would teach you.

Teach: What would you teach me?

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

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

Andy: Right.

[The discussion continues as the students explain their ideas about the composition of air and what it means to teach someone.]

Example 2: Same Student One Year Later

The following extract came from a grade 3 transcript of a small-group discussion. Two students, Jenny and Frank, were working together to produce a poster that encapsulated their explanation of the term idea.

[During the first five minutes of the assignment the two students discuss organizational procedures.]

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

Frank: 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.

Jenny: Ok. Lets 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?

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

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

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

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

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

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

Frank: 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. The two students return to the task at hand.]

Jenny: Ok. Hum (pause) we've got lots of things for the poster. <Frank: only four different thing.> Is that all? I think we have a lot more. <Frank: 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 <Frank: not so fast.> Ok. (long pause) [Frank reads back what he has written; then Jenny continues speaking.] and I think you use the ideas in your mind to think about other ideas because (pause)

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

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

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

Jenny: 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 <Frank: Yeah.> Like maybe they interfere like maybe some ideas interfere with other ideas.

Frank: 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] How's it going over here?

Frank: Good we got lots of good ideas.

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

Jenny: 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.

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

Jenny: [To teacher] Do you think Frank really put his ideas on the poster (pause) like if the ideas are in Frank'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.)

Even though the extracts presented above took place in a different setting (whole-class discussion vs. small-group discussion) the two can be compared. In the first extract, Jenny (grade 2), could express what in her opinion, constituted an idea. ("...a thought you may do...not do...explain to others...[or] just keep it to yourself"). Later during the class discussion Jenny tried to explain her thoughts about how ideas can sometimes be wrong ("...if someone is asking...question and you say yes when it's really no that's your idea of what it is..."). At this point in the conversation, it is not clear exactly what Jenny meant by this response. As the discussion develops she 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 the teacher ask Jenny why she did not get credit for the statement "two and two is five" Jenny responded she felt the teacher's idea was good because it was "what the teacher thought." However, Jenny indicated she could not agree with the teacher's idea as stated.

In the second extract, Jenny (grade 3), provided evidence that she had consolidated her explanation of what constitutes an idea. In addition, her discussion with Frank provides evidence of her epistemological beliefs in 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 you mind to think about other ideas...maybe some ideas interfere with other ideas...").

The two discussion taken as a whole, when compared, provide evidence that can be interpreted as an increase in Jenny's metacognitive capabilities. The unanswered question still remains: What caused or facilitated this increase in metacognitive ability?

Example 3

An extract from a grade 4 transcript of a whole-class discussion can be found in the appendix. The extract is included to give a sense of quality of the metacognitive capabilities of students who have been engaging in this type of discourse for four consecutive years. The printed segment consists of approximately the first fifteen minutes of a class discussion in which the students were trying to construct their own

understanding for the term intelligible. The segment is highly representative of: (a) the quality of metacognitive discussion that took place during the entire class period, and (b) the metacognitive capabilities displayed by this class through the course of the entire academic year.

Nature of Metacognitive Process

As stated earlier in this paper, one of the goals I hope to achieve through Project META is to understand the nature of metacognition more fully. A cursory analysis of students' classroom discourse showed: (a) that the students in question provided extensive and varied evidence of their metacognitive capabilities and (b) there was a significant difference in the type of metacognitive reflections produced. In order to better characterize the nature of this difference a framework was established for analyzing the students' metacognitive statements. A categorization scheme was developed to allow segments of discourse to be classified in terms of whether or not the student was:

- actively engaging in considering his or her own conceptions,
- able to explicitly refer to the reasoning used to support his or her own conceptions,
- explicitly considering the implications or limitations inherent in his or her own conceptions,
- explicitly referring to his or her own thinking or learning process,
- explicitly referring (or indirectly referring for students in grades 1-3) to the intelligibility, plausibility or fruitfulness of his or her conceptions,
- explicitly referring to any components of his or her conceptual ecology.

Discourse Analysis

It was hypothesized that the metacognitive discourse produced by students in this study were not equal in quality of metacognition. The method of data analysis and interpretation of discourse was undertaken with two purposes in mind. The first was to provide a procedure for breaking classroom discourse into segments which facilitated investigation of content. The second purpose was to review the discourse analysis to gage the extent to which the students' comments are metacognitive in nature.

It was necessary for the purposes of this investigation to accept that the categorizations of any student comment is highly inferential. The method of categorization of the discourse sample was twofold.

The first method involved a search of the discourse samples for segments that exemplified each of the categories. The selected segments were annotated with comments that described a learner's:

- propositional knowledge or belief claims about the science content under investigation,
- metaphysical beliefs about what is considered to be true about the real world or qualities of objects,
- references to the function of epistemological commitments (e.g., consistency in reasoning and generalizability of that reasoning to other circumstances, and
- explicit use of analogies, metaphors, real world prototypical exemplars or conceptual models.

This less rigorous analysis was considered to offer a breadth of coverage that could be regarded as sufficient for the purpose of informing or guiding the daily teaching routine and for characterizing the important attributes of metacognition. The second, and more demanding method, was to take each segment of discourse and classify it according to its cognitive level, that is, whether is was metacognitive or not. Any statements produced by either the students or teacher that were not metacognitive in nature and any metacognitive statements produced by the teacher were excluded from further classification. The remaining discourse segments were classified and assigned to one of the metacognitive categories listed above. Within each category, the metacognitive statements were sub-classified by annotative comments (e.g., statements that referred to: causal mechanism, past experiences, consistency with other knowledge, or statements in that included evidence of the student's ability to represent his or her conceptions by employing analogies, images, models). The analytical framework developed by Thorley (1990) for using the conceptual change model to interpret transcripts of classroom discourse proved to be extremely useful as a guide to for annotating and sub-classifying student metacognitive comments. Application of the second, and more demanding, method of analysis was used on a limited bases for the purpose of informing the questions posed in this study. For purpose of clarification both methods of data analysis are provided in the section below.

Categories of Metacognitive Reflection

In this section, the categories of metacognitive discourse will be briefly discussed and examples of student discourse, which are rich in metaconceptual references, are provided for purpose of clarification. Efforts were made to select examples of student thinking or reasoning that reflected the canonical as well as

the non-canonical view of science.

Examples of Students' Statements That Explicitly Refer Their Own Conceptions.

Included in this category are metacognitive statements in which a student explicitly refers to his or her own conception or a peer's conception. The ability to explicitly think about the ideas or conceptions one holds or is currently considering (assuming there is some external representation of that conceptions) is a minimal requirement for students' 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.

Example 1

Context. The following extract came from a transcript of a grade six small-group discussion. The focus of the discussion was the book on the table task in which the students were asked to give a force explanation from a list of options (six pictures representing possible force combinations acting on the book as it rested on the table).

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).

Annotated comments. Andy's comments display evidence that he is capable of describing his ideas about the force 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."

Example 2

Context. The following extract came from a transcript of a grade one whole-class discussion. 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).

Annotated comments. Jenna's comments display evidence 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).

Example 3

Context. The following extract came from a grade six small-group discussion and is an example of a student explicitly referring to a peer's conception. The discussion focused on th : 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).

Annotated comments. 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, namely, that constant velocity is possible with balanced forces.

Example 4

Context. The last example given in this section came from a transcript of a grade two whole-class discussion. The focus of the discussion was on students' ideas about what they think happens to a solid as it dissolves in a liquid. The students performed a simple task: filled two jars with the same amount of water, emptied 1 packet of sugar into each jar. and place a lid on one of the jars. 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).

Annotated comments. Eric reveals his theory 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").

Examples of Students' Statements That Explicitly Refer to the Reasoning Behind Their Conceptions

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

Example 1

Context. 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.

	Brianna's Comments	Classification Sub-Categories
T:	Would anyone like to predict what they think will happen to these stones. Yes, Briana.	Teacher remarks
B:	I think the both stones will sink because I know stones sink (pause).	Represents concept Refers to own knowledge
	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)	Refers to past experiences
T:	You look like you want to say something else.	Teacher remarks
B:	(Pause) Yeah the water can't hold up rocks like it holds up boats and I know they'll [stones] sink <Peer: Yeah>	Reveals metaphysical belief about water Uses example to support belief
T:	You sound so sure, let me try another object.	Teacher remarks
B:	No you gotta throw it in, you gotta test my idea first.	Refers to lab test experience
[Small stone is placed in the tank--it sinks] <peers: cheers.>		Teacher action

B:	See, I told you I knew it would sink.	Refers to consistency with knowledge
[Teacher places larger rock down and picks up another object.]		Teacher action
B:	No you've gotta test the big one too because if the little one sunk the big one's gotta sunk (sic).	Refers to lab test experience Reveals reasoning
[Larger stone is placed in the tank--it floats.]		Teacher action
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).	Considers this an anomalous event Reveals inconsistency with previous knowledge

Example 2

Context. 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's Comments	Classification Sub-Categories
My Past Ideas. In the past I thought for instance the BOOK ON THE TABLE had only 1 force, and that force was gravity.	Reveals past theory
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.	Reveals past metaphysical belief about the nature of living / non-living
However, my ideas have changed since the beginning of this year.	Explicitly states change in ideas
Sr. helped me to see the difference between the macroscopic level and the microscopic level, that was last year.	Explains how ideas became understood
But I never really thought about that difference very much.	Compensation argument
Then this year I began to think about the book on the table differently--	Aware of shift in thinking
then [last school year] I was thinking on the macroscopic level and	Compensation argument

not on the microscopic level.	Explains how ideas became understood
This year I wasn't looking at the table from the same perspective as last year.	Reveals shift in focus of thinking
Last year I was looking at living being the import focus and now I am looking at the molecules as being the important focus.	Acknowledges conceptual change Reveals shift in metaphysical beliefs
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.	Explicit reference to construction of knowledge takes time to achieve
It took me a whole YEAR to figure this concept out!!! Now I know it was worth THE YEAR to figure this out	Application of theory
because now I can see balanced forces everywhere! Balanced forces are needed to produce constant velocity!	Generalizes theory to new situation
The book on the table has a velocity of zero, that means it has a steady pace of zero.	Explains how ideas became understood
Why, Sr. asks did my ideas change? I think my ideas changed because I have expanded my mind to more complicated ideas!	Reveals a metaphysical belief in the nature of molecules--they can cause an effect
Like molecules in a table can have an effect on a book,	Reveals an epistemological belief about the nature of an explanation that some things are more important to consider that others
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).	

Annotated comments. Jill's response to the statement above demonstrates her ability to go beyond mere recognition of her personal constructs to comment on why 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 two balanced forces instead of just gravity..."). 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).

Examples of Students' Statements That Explicitly Refer to the Implications or Limitations Inherent in Their Conceptions

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 or her conceptions, or (2) show 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, 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.

Example 1

Context. 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).

Annotated comments. 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...").

Examples of Students' Statements That Explicitly Refer to Their Thinking or Learning Process.

Segments of metacognitive discourse assigned to this category are clearly indicative of the students' abilities to reflect on his or her thinking or learning process as an objects of cognition.

Example 1

Context. 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.

Annotated comments. 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.

Examples of Students' Statements that Explicitly Refer to the Status of a 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 (intelligible, plausible, fruitful).

Example 1

Context. 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.

Annotated comments. 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..."). 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...").

Examples of Students' Statements that Explicitly Refer to the Components of Their Conceptual Ecology.

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.

Example 1

Context. 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.

Annotated comments. In this case, Melinda readily acknowledges that the conceptions 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 how molecules could possible move).

Discussion

Selected samples of discourse from six different grade levels which had a strong conceptual change orientation have been interpreted to illuminate the nature of metacognitive interactions among elementary students and the possible role metacognition plays in conceptual knowledge development.

First the data has been interpreted to show that the students in question can provide extensive and varied evidence of their metacognitive capabilities. Analysis of lengthy segments of classroom interactions shows that both the teacher and the students have created a highly interactive, conceptually oriented learning environment. Evidence exists that the focus of learning was the elicitation and development of students understanding of conceptions. The stated learning goals and their explicit implementation in a classroom setting suggest that curricula followed in this classroom is the content of the students' conceptions about the science topic under consideration. This stands in direct contrast with curricula that focuses on the "correct" scientific view and a teaching process that presents the scientific view logically and didactically. Evidence

from the data clearly supports the conclusion that one way to explicitly promote metacognition in individual students or within the classroom is to create a learning environment in which both students and teacher actively engage in thinking about their conceptions of the science topic under consideration as an object of cognition, rather than merely reflecting on correct scientific view. The act of "explicitly thinking about one's conceptions as an object of cognition" has been interpreted by me to encompass multiple aspects:

- considering multiple way of representing personal constructs or knowledge claims,
- making public the reasoning used to support personal construct or knowledge claims,
- explicitly considering the implications and limitations inherent in personal knowledge claims,
- considering the intelligibility, plausibility and fruitfulness of one's personal ideas about the topic under consideration in relationship to the intelligibility, plausibility and fruitfulness of an alternate and perhaps contradictory view of the topic under consideration, and
- looking for some consistency and generalizability among one's beliefs.

The question of the role that classroom discourse plays in facilitating the development of metacognition in students is best answered by evidence from a control study. However, it is within the scope of this study, to interpret the available data by making some comparison. When making a comparison among segments of metacognitive discourse taken from second, third and fourth graders and making a similar comparison between segments of metacognitive discourse produced by individual students over consecutive years, a qualitative difference is noted in each comparison. At this point in the data analysis, it is only possible to suggest that perhaps the qualitative differences are due to the fact that students become more facile at being metacognitive over time.

In order to address the question about the nature of the metacognitive process within the science classroom, a system of categories for the analysis of the content of the discourse has been outlined. Data analysis indicates extensive evidence of a qualitative difference in the types of metacognitive statements produced by the students in this study. Analysis of these qualitative difference shows a broad range in students' metacognitive capabilities. The following ranges were noted. It was recognized that the student, on the whole, had no difficulty representing or communicating their conceptions. Over time that

communication entailed the use of reasoning to support their conceptions, use of descriptors in terms of attributes as well as the enumeration of prototypical exemplars, or the use of models of external representation. This range was further extended, over time, to include elaborations of the basis of judgements, a sense of causal mechanism, and a search for consistency of fit with the reality of a conception.

The last question addressed in this study is the role of metacognition in facilitating conceptual knowledge development. It is not within the scope of this study to directly document the number and kind of conceptual changes (i.e., changes in the form of conceptual capture as well as conceptual exchange) which taken place within the mind of the learner. Rather, the focus is on documenting ways in which students indicate their conceptions have changed. For example, the statement made by Jill "...My ideas have changed because I have expanded my mind to more complicated ideas!" or the two statement made by Eamon "...I have to decide what to do with what I hear. I have to see where it fits in with the ideas in my mind." and " An ideas that isn't plausible...isn't going to change to plausible all by itself. I have to get more pieces...I have to make the not plausible idea plausible and some ideas I won't even try to it make plausible because they just don't make any real sense..." are far more revealing about the nature of conceptual change than statements like "I changed my mind, the table can produce a force." It is within the context of revealing these statements that the metacognitive capabilities of the student in this study serves as a facilitator of conceptual knowledge development.

Appendix 1

The following is an extract of approximately 15 minutes from a transcript of a fourth grade class discussion on the meaning of the term intelligible. An integral part of defining any new terms for the students at the research site is to negotiate by consensus an understanding for the term in question. The students are involved and are interested in each others' comments. They are able to maintain over a considerable period of time a student-to-student discussion without the teacher acting as a chairperson, nor as in the case of younger students, filtering all comments through the teacher.

Teach: Alright yesterday you were trying to building an understanding for this word [refers to word on poster] up here called intelligible.

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

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

Alli: Yeah! There is 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 you mind [interrupted]

Eamon: Picture in your mind, picture in your mind [interrupted]

Bliss: And thinking about it [interrupted]

Eamon: You can say it. Like you have a picture in your mind and then you never (pause) like, it's really, (pause) like, you don't really under (pause) your not really (pause) like you don't (pause) like like right now. I've got something in my mind and I'm trying to talk about it. Right? But it's really hard.

Bliss: Why?

Alli: 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]

Alli: Yeah. But I don't think models 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.

Teach: To understand. (Pause) Raise you hand if you feel comfortable with that idea, would you. (Pause). Alright, you can put your hand down. Can you raise you hand if you don't feel comfortable with that meaning. To the people is this group the question is: Do you think the word is better described by some other way? That's a thought question. Keep in mind that we are just trying to find ways of describing this word. Ways in which people feel comfortable with it at this early stage. Eventually we'll make a definition like we usually do other words. Kathryn, do you have anything you would like to say? (Pause)

Kath: The word understand just does say the right think to me yet.No, but I can't find anything else to replace it.

Teach: Ok. If you do jump back in on the conversation. Anybody else? Lucas.

Lucas: Like to experience.

Teach: Ok. To experience? Can you tell me a little bit more by what you mean by that?

Lucas: Like to hum (pause) like experience (pause) hum.(pause) experience like what you know. (pause) You need experiences to know you understanding something (pause). Intelligible has to do with experiences and I think it has to do with trying to show a person (pause) I think experiences and telling or showing is important for intelligible (pause) but I can't say why just yet.

Adam: The dictionary said it was that you are capable of understanding.

Chel: That you can understand clear.

Eamon: They all have something to do with understand.

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.

MichQ: But I like that one.

Chel: And I like that one.

Alli: 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.

Alli: 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 make 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

Class: [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 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]

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.

Alli: 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?

Class: Yes.

Adam: We're in school

Class: (Laughs)

David: Ok. How about the words school swims?

Class: (Several talking at once)

Teach: Ok. Lets go one at a time. School swims.

Stdt: I doesn't make sense.

Alli: 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: It's 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.

Mlinda: Besides schools are dead.

Stdts: (Several talking all at once).

Teach: Ok. One at a time please.

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?

Class: [Several voices] Yes. Yeah.

Jack: You can put that with hum, like curtains don't eat and schools don't swim. [Interrupted]

MichQ: Well, it's like your brain I mean, you can't, I mean you'll think about it and lets say you go: it doesn't make sense. And we will go right because we have heard that before right. 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

Class: (Several talking at once)

Mlinda: Like I don't picture a school having arms and legs going stroke, slash.

Class: (Laughs)

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

Mlinda: But Eamon, that 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 is intelligible. (Pause) Like does the words school swims communicate a sensible idea?

Class: [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.

Teach: May I have you attention please. Lets see if we can move forward. Perhaps you may want to think about what you choose to focus in on. Ok. Sometimes you don't understand something. So listen: ¿Como te llama?

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